GEOLOGY OF INDIA

FOR STUDENTS

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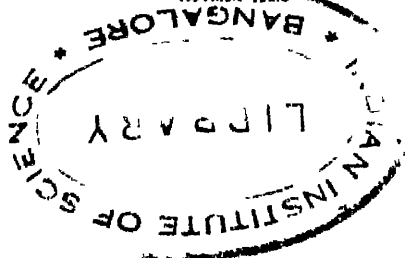
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IN HEAVEN,

WHOSE MEMORY HAS INSPIRED THE PUBLICATION,

THESE PAGES ARE INSCRIBED.

PREFACE

As a lecturer in Geology to students preparing for the Punjab University Examinations I have constantly experienced great difficulty in the teaching of the Geology of India, because of the absence of any adequate modern book on the subject The only work that exists is the one published by the Geological Survey of India in 1887, by H B Medlicott and W T. Blanford, revised and largely rewritten by R D. Oldham in 1893—a quarter of a century ago Although an excellent official record of the progress of the Survey up to that time, this publication has naturally become largely out of date (now also out of print) and is, besides, in its voluminous size and method of treatment, not altogether suitable as a manual for students preparing for the University Examinations. Students, as well as all other inquirers, have, therefore, been forced to search for and collect information, piecemeal, from the multitudinous *Records* and *Memoirs* of the Geological Survey of India. These, however, are too numerous for the diligence of the average student—often, also, they are inaccessible to him—and thus much valuable scientific information contained in these admirable publications was, for the most part, unassimilated by the student class and remained locked up in the shelves of a few Libraries in the country. It would not be too much to say that this lack of a handy volume is in the main responsible for the almost total neglect of the Geology of India as a subject of study in the colleges of India and as one of independent scientific inquiry.

The object of the present volume is to remedy this deficiency by providing a manual in the form of a modern text-book, which summarises all the main facts of the subject within a moderate compass. It is principally a compilation, for the use of the students of Indian Geology, of all that has

been published on the subject, especially incorporating the later researches and conclusions of the Geological Survey of India since Oldham's excellent edition of 1893

In a subject of such proportions as the Geology of India, and one round which such voluminous literature exists, and is yearly growing, it is not possible, in a compendium of this nature, to aim at perfection of detail Nor is it easy, again, to do justice to the devoted labours of the small body of original workers who, since the '50's of the last century, have made Indian Geology what it is to-day. By giving, however, in bold outlines, the main results achieved up to date and by strictly adhering to a text-book method of treatment, I have striven to fulfil the somewhat restricted object at which I have aimed

In the publication of this book I have received valuable help from various quarters. My most sincere thanks are due to Sir T. H Holland, F R.S , D Sc , for his warm sympathy and encouragement. To Dr E. H. Pascoe, D Sc., Director of the Geological Survey of India, I offer my grateful acknowledgments for the loan of blocks and plates from negatives for the illustrations in the book, and for permission to publish this volume. My indebtedness to Mr. C. S. Middlemiss, C.I E., F.R.S , retired Superintendent of the Geological Survey of India, the *doyen* of Indian Geologists, I can never sufficiently acknowledge. His guidance and advice in all matters connected with illustrations, correction of manuscript and text, checking of proofs, etc., have been of inestimable value. Indeed, but for his help several imperfections and inaccuracies would have crept into the book. I have also to offer my warm thanks to Dr. G E Pilgrim, D.Sc., for his helpful criticisms and valuable suggestions in revising the Tertiary Systems

In the end, I tender my grateful acknowledgments to Messrs Macmillan for their uniform courtesy.

D N. WADIA.

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CHAPTER I

PHYSICAL FEATURES

BEFORE commencing the study of the stratigraphical geology of India, it is necessary to acquire some knowledge of the principal physical features. The student should make himself familiar with the main aspects of its geography, the broad facts regarding its external relief or contours, its mountain-systems, plateaus and plains, its drainage-courses, its glaciers, volcanoes, etc. This study, with the help of physical or geographical maps, is indispensable. Such a foundation-knowledge of the physical facts of the country will not only be of much interest in itself, but the student will soon find that the physiography of India is in many respects correlated to, and is, indeed, an expression of, its geological structure and history

Geological divisions of India.

The most salient fact with regard to both the physiography and geology of the Indian region is that it is composed of three distinct units or earth-features, which are as unlike in their physical as in their geological characters The first two of these three divisions of India have a fundamental basis, and the distinctive characters of each, as we shall see in the following pages, were impressed upon it from a very early period of its geological history, since which date each area has pursued its own career independently. These three divisions are :

1. The triangular plateau of the *Peninsula*, with the island of Ceylon.

2. The mountainous region which borders India to the west, north, and east, including the countries of Afghanistan, Baluchistan, and the hill-tracts of Burma, known as the *extra-Peninsula*.

3. The great *Indo-Gangetic Plain* of the Punjab and Bengal, separating the two former areas, and extending from the valley of the Indus in Sind to that of the Brahmaputra in Assam.

Their characters and peculiarities

As mentioned above, the Peninsula, as an earth-feature, is entirely unlike the extra-Peninsula. The following differences summarise the main points of divergence between these two regions: The first is *Stratigraphic*, or that connected with the geological history of the areas. Ever since the Cambrian period, the Peninsula has been a land area, a continental fragment of the earth's surface, which since that epoch in earth-history has never been submerged beneath the sea, except temporarily and locally. No considerable marine sediment of later age than Cambrian was ever deposited in the *interior* of this land-mass. The extra-Peninsula, on the other hand, has been a region which has lain under the sea for the greater part of its history, and has been covered by successive marine deposits of all the great geological periods, commencing with the earliest, Cambrian.

The second difference is *geotectonic*, or pertaining to the geological structure of the two regions. The Peninsula of India reveals quite a different type of architecture of the earth's crust from that shown by the extra-Peninsula. Peninsular India is a segment of the earth's outer shell that is composed in great part of generally horizontally reposing rock-beds that stand firm and immovable upon a deep-seated foundation and that have, for an immense number of ages, remained so—impassive and undisturbed amid all the revolutions that have again and again changed the face of the earth. Lateral thrusts and mountain-building forces have had but little effect in folding or displacing its originally horizontal strata. The extra-Peninsula, on the contrary, is a portion of what appears to have been a comparatively weak and flexible portion of the crust that has undergone a great deal of crustal deformation. Rock-folds, faults, thrust-planes, and other evidences of movements within the earth are observed in this region on an extensive scale, and they point to its being a portion of the earth that has

undergone, at a late geological epoch, an enormous amount of compression and upheaval. The strata everywhere show high angles of dip, a closely packed system of folds, and other violent departures from their original primitive structure.

The third difference is the diversity in the *physiography* of the two areas. The difference in the external or surface relief of Peninsular and extra-Peninsular India arises out of the two above-mentioned differences, as a direct consequence In the Peninsula, the mountains are mostly of the "Relict" type, i.e. they are not mountains in the true sense of the term, but are mere outstanding portions of the old plateau of the Peninsula that have escaped, for one reason or another, the weathering of ages that has cut out all the surrounding parts of the land, they are, so to say, huge "tors" or blocks of the old plateau. Its rivers have flat, shallow valleys, with low imperceptible gradients, because of their channels having approached to the base-level of erosion. Contrasted with these, the mountains of the other area are all true mountains, being what are called "tectonic" mountains, i.e. those which owe their origin to a distinct uplift in the earth's crust and, as a consequence, have their strike, or line of extension, more or less conformable to the axis of that uplift The rivers of this area are rapid torrential streams, which are still in a very immature stage of river development, and are continuously at work in cutting down the inequalities in their courses and degrading or lowering their channels. Their eroding powers are always active, and they have cut deep gorges and precipitous cañons, several thousands of feet in depth, through the mountains in the mountainous part of their track.

Types of the earth's crust exemplified by these divisions.

The type of crust segments of which the Peninsula is an example, is known as a *Horst*—a solid crust-block which has remained a stable land-mass of great rigidity, and has been unaffected by any folding movement generated within the earth during the later geological periods. The only structural disturbances to which these parts have been susceptible are of the nature of vertical, downward or upward, movements of large segments within it, between vertical (radial) fissures or faults. The Peninsula has often

experienced this "block-movement" at various periods of its history, most notably during the Gondwana period.

The earth-movements characteristic of the flexible, more yielding type of the crust, of which the extra-Peninsula is an example, are of the nature of lateral (*i.e tangential*) thrusts which result in the wrinkling and folding of more or less linear zones of the earth's surface into a mountain-chain (orogenic movements). These movements, though they may affect a large surface area, are solely confined to the more superficial parts of the crust, and are not so deep-seated as the former class of movements characteristic of horsts

Physical characters of the plains of India.

The third division of India, the great alluvial plains of the Indus and the Ganges, though, humanly speaking, of the greatest interest and importance, as being the principal theatre of Indian history, is, geologically speaking, the least interesting part of India. In the geological history of India they are only the annals of yester-year, being the alluvial deposits of the rivers of the Indo-Ganges systems, borne down from the Himalayas and deposited at their foot. They have covered up, underneath a deep mantle of river-clays and silts, valuable records of past ages, which might have thrown much light on the physical history of the Peninsular and the Himalayan areas, and revealed their former connection with each other. These plains were originally a deep depression or furrow lying between the Peninsula and the mountain-region. With regard to the origin of this great depression there is some difference of opinion. The eminent geologist, Eduard Suess, thought it was a "Fore-deep" fronting the Himalayan earth-waves, a "sagging" or subsidence of the northern part of the Peninsula, as it arrested the southward advance of the mountain-waves. Colonel Sir S Burrard, from some anomalies in the observations of the deflections of the plumb-line, and other geodetic considerations, has suggested quite a different view.[1] He thinks that the Indo-Gangetic alluvium conceals a great deep rift, or fracture, in the earth's sub-crust, several thousand feet deep, the hollow being subsequently filled up by detrital deposits. He ascribes to such sub-crustal cracks

[1] *The Origin of the Himalayas*, 1912 (Survey of India Publication). *Presidential address*, the Indian Science Congress, Lucknow, 1916.

or rifts a fundamental importance in geotectonics, and attributes the elevation of the Himalayan chain to an incidental bending or curling movement of the northern wall of the fissure. Such sunken tracts between parallel, vertical dislocations are called "Rift-Valleys" in geology. The geologists of the Indian Geological Survey have not accepted this view of the origin of the Indo-Gangetic depression [1]

Rajputana a debatable area.

The large tract of low country, forming Rajputana, west of the Aravallis, possesses a mingling of the distinctive characters of the Peninsula, with those of the extra-Peninsula, and hence cannot with certainty be referred to either. Rajputana can be regarded as a part of the Peninsula inasmuch as in geotectonic characters it shows very little disturbance, while in its containing marine, fossiliferous deposits of Mesozoic and Cainozoic ages it shows greater resemblance to the extra-Peninsular area In this country, long-continued aridity has resulted in the establishment of a desert topography, buried under a thick mantle of sands disintegrated from the subjacent rocks as well as blown in from the western sea-coast and from the Indus basin. The area is cut off from the water-circulation of the rest of the Indian continent, except for occasional storms of rain, by the absence of any high range to intercept the moisture-bearing south-west monsoons which pass directly over its expanse The desert conditions are hence accentuated with time, the water-action of the internal drainage of the country being too feeble to transport to the sea the growing mass of sands.

There is a tradition, supported by some physical evidence, that the basin of the Indus was not always separated from the Peninsula by the long stretch of sandy waste as at present. "Over a vast space of the now desert country, east of the Indus, traces of ancient river-beds testify to the gradual desiccation of a once fertile region; and throughout the deltaic flats of the Indus may still be seen old channels which once conducted its waters to the Rann of Cutch, giving life and prosperity to the past cities of the delta, which have left no

[1] See Dr. Hayden, "Relationship of the Himalaya to the Indo-Gangetic Plain and the Indian Peninsula," *Rec. G.S I.* vol. xliii. pt. 2, 1915, and R. D. Oldham, *Mem. G.S.I.* vol. xlii. pt. 2, 1917.

living records of the countless generations that once inhabited them "[1]

MOUNTAINS

The mountain-ranges of the extra-Peninsula have had their origin in a series of earth-movements which proceeded from outside India. The great horst of the Peninsula, composed of old crystalline rocks, has played a large part in the history

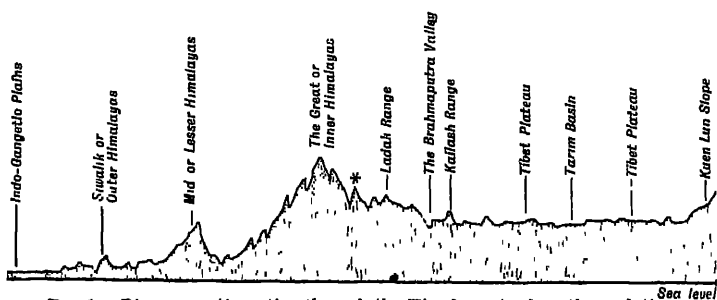



FIG 1 —Diagrammatic section through the Himalayas to show their relations to the Tibet Plateau and the plains of India
* Watershed of the Himalayas (Vertical scale greatly exaggerated.)

of mountain-building movements in Northern India. It has limited the extent, and to some degree controlled the form of the chief ranges Broadly speaking, the origin of the Himalayan chain, the most dominant of them all, is to be referred to powerful lateral thrusts acting from the north or Tibetan direction towards the Peninsula of India. These thrusting movements resulted in the production of fold after fold of the earth's crust, pressing against the Peninsula. The curved form of the Himalaya [2] is due to this resistance offered by the Peninsular "foreland" to the southward advance of these crust-waves, aided in some measure by two other minor obstacles—the Salt-Range mountains to the north-west and the Assam ranges to the north-east [3] The general configuration of the Himalayan chain, its north-west south-east trend, the abrupt steep border which it presents to the plains of India

The Himalaya mountains.

[1] Sir T H Holdich, *Imperial Gazetteer*, vol. i

[2] From Sanskrit, *Him Alaya*, meaning the abode of snow

[3] Another view is that the curvature is the result of the interference of similar folding movements proceeding from the Iranian or the Hindu Kush system of mountains.

with the much more gentle slope towards the opposite or Tibetan side, are all features which are best explained, on the above view, as having been due to the resistances the mountain-making forces had to contend against in the Peninsula and in the two other hill-ranges. The convex side of a mountain range is, in general, in the opposite direction to the side from which the thrusts are directed, and is the one which shows the greatest amount of plication, fracture, and overthrust. This is actually the case with the outer or convex side of the Himalayas, in which the most characteristic structural feature is the existence of a number of parallel, reversed faults, or thrust-planes. The most prominent of these fractures, the outermost, can be traced from the Punjab Himalayas all through the entire length of the mountains to their extremity in East Assam. This great fault or fracture is known as the Main Boundary Fault.

Physical features of the Himalayas

The geography of a large part of the Himalayas is not known, because immense areas within it have not yet been explored by scientists; much therefore remains for future observation to add (or alter) in our existing knowledge. Lately, however, the three Mt. Everest expeditions have made additions to our knowledge of large tracts of Eastern Himalayas. The Himalayas are not a single continuous chain or range of mountains, but a series of several more or less parallel, or converging ranges, intersected by enormous valleys and extensive plateaus. Their width is between 100 and 150 miles, comprising many minor ranges. The individual ranges generally present a steep slope towards the plains of India and a more gently inclined slope towards Tibet. The northern slopes are, again, clothed with a thick dense growth of forest vegetation, surmounted higher up by never-ending snows, while the southern slopes are too precipitous and bare either to accumulate the snows or support, except in the valley basins, any but a thin sparse jungle. The starting point of the Himalayan system is situated in the Pamir plateau ("the roof of the world"), which is a knot or nucleus from which also diverge all the principal ranges of Central Asia. From the Pamirs to the south-east, the Himalayas extend as an unbroken wall of snow-covered mountains, pierced by passes, none of which are less than 17,000 feet in elevation. The Eastern Himalayas of Nepal and Sikkim rise very abruptly from the

plains of Bengal and Oudh, and suddenly attain their great elevation above the snow-line within strikingly short distances from the foot of the mountains Thus, the peaks of Kinchinjunga and Everest (Gaurishankar) are only a few miles from the plains and are visible to their inhabitants But the Western Himalayas of the Punjab and Kumaon rise gradually from the plains by the intervention of many ranges of lesser altitudes, their peaks of everlasting snows are more than a hundred miles distant, hidden from view by the mid-Himalayan ranges to the inhabitants of the plains.

Meteorological influence of the Himalayas

This mighty range of mountains exercises as dominating an influence over the meteorological conditions of India as over its physical geography, vitally affecting both its air and water-circulation. Its high snowy ranges have a moderating influence on the temperature and humidity of Northern India. By reason of its altitude and its situation directly in the path of the monsoons, it is most favourably conditioned for the precipitation of all their contained moisture, either as rain or snow. Glaciers of enormous magnitude are nourished on the higher ranges by this precipitation, which, together with the abundant rainfall of the lower ranges, feed a number of rivers, which course down to the plains in hundreds of fertilising streams. In this manner the Himalayas protect India from the gradual desiccation which is overspreading the Central Asian continent, from Tibet northwards, and the desert conditions that inevitably follow continental desiccation.

Geographically, the Himalayas are generally considered to terminate, to the north-west, at the great bend of the Indus, where it cuts through the Kashmir Himalayas, while the south-eastern extremity is defined by the similar bend of the Brahmaputra in upper Assam. At these points also there is a well-marked bending of the strike of the mountains from the general north-west—south-east, to approximately north and south direction. Some geographers have refused to accept this limitation of the Himalaya mountain system, because according to them it ignores the essential physical unity of the hill-ranges beyond the Indus and the Brahmaputra with the Himalayas They would extend the term Himalayas to all those ranges to the east and west (*i.e.* the Hindu-Kush

mountains and some ranges of Burma) which originated in the same great system of Pliocene orogenic upheavals.

Classification of the Himalayan Ranges.

(I) **Geographical.**—For geographical purposes the Himalayan system is classified into three parallel or longitudinal zones, each differing from one another in well-marked orographical features.

(1) The *Great Himalayas*: the innermost line of high ranges, rising above the limit of perpetual snow. Their average height extends to 20,000 feet; on it are situated the peaks, like Mount Everest, K_2, Kinchinjunga, Dhavalagiri, Nanga Parbat, Gasherbrum, Gosainthan, Nanda Devi,[1] etc.

(2) The *Lesser Himalayas*, or the middle ranges: a series of ranges closely related to the former but of lower elevation; seldom rising much above 12,000–15,000 feet. The Lesser Himalayas form an intricate system of ranges, their average width is fifty miles

(3) The *Outer Himalayas*, or the *Siwalik ranges*, which intervene between the Lesser Himalayas and the plains. Their width varies from five to thirty miles. They form a system of low foot-hills with an average height of 3000–4000 feet.

(II.) **Geological.**—As regards geological structure and age the Himalayas fall into three broad stratigraphical belts or zones. These zones do not correspond to the geographical zones as a rule.

(1) The Northern or *Tibetan Zone*, lying behind the line of highest elevation (*i.e.* the central axis corresponding to the great Himalayas). This zone is composed of a continuous series of highly fossiliferous marine sedimentary rocks, ranging in age from the earliest Palaeozoic to the Eocene age. Except

[1]

Mount Everest (Gaurishankar)	Nepal Himalayas	29,000 ft.
K_2	Karakoram	28,250 ,,
Kinchinjunga	Nepal Himalayas	28,100 ,,
Dhavalagiri	,,	26,800 ,,
Nanga Parbat	Kashmir Himalayas	26,600 ,,
Gasherbrum	Karakoram	26,470 ,,
Gosainthan	Nepal Himalayas	26,291 ,,
Nanda Devi	Kumaon Himalayas	25,650 ,,
Rakaposhi	Kailas range	25,550 ,,

(Col. Burrard.)

near the north-western extremity (in Hazara and Kashmir) rocks belonging to this zone are not known to occur south of the line of snowy peaks.

(2) The Central or *Himalayan Zone*, comprising most of the Lesser or Middle Himalayas together with the Great Himalayas. It is mostly composed of crystalline and metamorphic rocks—granites, gneisses, and schists, with unfossiliferous sedimentary deposits of very ancient (Purana) age

(3) The Outer or *Sub-Himalayan Zone*, corresponding to the Siwalik ranges, and composed entirely of Tertiary, and principally of Upper Tertiary, sedimentary river-deposits

The above is a very brief account of a most important subject in the geography of India, and the student must refer to the works mentioned at the end of the chapter for further information, especially to that by Colonel Burrard and Dr Hayden, which contains the most luminous account of the geography and the geology of the Himalayas.

Other ranges of the extra-Peninsula

Running transversely to the strike of the Himalayas at either of its extremities, and by some authorities believed to belong to the same system of upheaval, are the other minor mountain-ranges of extra-Peninsular India Those to the west are the flanking ranges which form the Indo-Afghan and Indo-Baluchistan frontier. Those to the east are the mountain-ranges of Burma. Many of these ranges have an approximate north-to-south trend The names of these important ranges are·

WEST.	EAST.
The Hindu-Kush.	The Assam ranges
The Salt-Range	The Manipur ranges
The Suleiman range.	The Arakan Yoma
The Bugti range.	The Tenasserim range
The Kirthar range.	

With the exception of the Hindu-Kush, the Salt-Range and the Assam ranges, the other mountains are all of a very simple type of mountain-structure, and do not show the complex inversions and thrust-planes met with in the Himalayas. They are again principally formed of Tertiary rocks. The Salt-Range and the Assam ranges, however, are quite different,

and possess several unique features which we shall discuss later on. Their rocks have undergone a greater amount of fracture and dislocation, and they are not composed so largely of Tertiary rocks.

The important mountain ranges of the Peninsula are The Aravalli mountains, the Vindhyas, Satpuras, the Western Ghats (or, as they are known in Sanskrit, the Sahyadris), and the irregular broken and discontinuous chain of elevations known as the Eastern Ghats Of these, the Aravallis are the only instance of a true tectonic mountain-chain, all the others (with one possible exception to be mentioned below) are merely mountains of circumdenudation, *i.e.* they are the outstanding remnants or outliers, of the old plateau of the Peninsula that have escaped the denudation of ages Not one of them shows any axis of upheaval that is coincident with their present strike. Their strata show an almost undisturbed horizontality, or, at most, very low angles of dip. The Aravallis were a prominent feature in the old Palaeozoic and Mesozoic geography of India, and extended as a continuous chain of lofty mountains from the Deccan to possibly beyond the northern limit of India What we at present see of them are but the deeply eroded remnants of these mountains, their mere stumps laid bare by repeated cycles of erosion.

The Mountain ranges of the Peninsula

The rocky country which rises gradually from the south of the Gangetic plains culminates in the highlands of Central India, comprising Indore, Bhopal, Bundelkhand, etc The southern edge of this country is a steep line of prominent escarpments which constitute the Vindhyan mountains, and their easterly continuation, the Kaimur range Their elevation is between 2500–4000 feet above the sea-level. The Vindhyas are for the most part composed of horizontally bedded sedimentary rocks of ancient age, the contemporaries of the Torridon sandstone of Scotland. South of the Vindhyas, and roughly parallel with their direction, are the Satpura mountains. The name *Satpura,* meaning "seven folds," refers to the many parallel ridges of this mountain The chain of ridges commences from Rewah, runs south of the Narbada valley and north of the Tapti valley, and stretches westwards through the Rajpipla hills to the Western Ghats. The

Vindhya mountains.

Satpura range.

Vindhya and the Satpura chains form together the backbone of middle India. A very large part of the Satpuras, the western and eastern parts, are formed of Cretaceous basalts ; the central part is composed, in addition to a capping of the traps, of a core of granitoid and metamorphic rocks, overlaid by Mesozoic sandstones Some parts of the Satpuras give proof of having been folded and upheaved, the strike of the folding showing a rough correspondence with the general direction of the range It is probable, therefore, that the Satpuras are, like the Aravallis, a weather-worn remnant of an old tectonic chain

The Western Ghats.

The greater part of the Peninsula is constituted by the Deccan plateau. It is a central tableland, extending from 12° to 21° North Latitude, rising about 2000 feet mean elevation above the sea, and enclosed on all sides by hill-ranges To its west are the Sahyadris, or Western Ghats, which extend unbroken to the extreme south of Malabar, where they merge into the uplands of the Nilgiris, some of whose peaks rise to the altitude of 8700 feet above the sea-level (Dodabetta peak), the highest point of the Peninsula From the Nilgiris the Western Ghats extend (after the solitary opening, Palghat Gap), through the Anaimalai hills, to the extreme south of the Peninsula. The Western Ghats, as the name Ghat denotes, are, down to Malabar, steep-sided, terraced, flat-topped hills or cliffs facing the Arabian sea-coast and running with a general parallelism to it. Their mean elevation is some 3000 feet. The horizontally bedded lavas of which they are wholly composed have, on weathering, given to them a characteristic "landing-stair" aspect. This peculiar mode of weathering imparts to the landscapes of the whole of the Deccan a strikingly conspicuous feature. The physical aspect of the Western Ghats south of Malabar—that is, the portion comprising the Nilgiris, Anaimalai, etc.—is quite different from these square-cut, steep-sided hills of the Deccan proper. The former hills are of a more rounded and undulating outline, clothed under a great abundance of indigenous, sub-tropical forest vegetation. The difference in scenery arises from the difference in geological structure and composition of the two portions of the Western Ghats.

Beyond Malabar they are composed of the most ancient massive crystalline rocks, and not of horizontal layers of lava-flows.

The Eastern Ghats

The broken and discontinuous line of mountainous country, facing the Bay of Bengal, and known as the Eastern Ghats, has neither the unity of structure nor of outline characteristic of a mountain-chain. They belong to no one geological formation, but the rocks vary with the country through which they pass, being made of several units, which are formed of the steep scarps of several of the South Indian formations. Some of these scarps are the surviving relics of ancient mountain-chains elevated contemporaneously with the Aravallis

Among the remaining, less important, hill ranges of the Peninsula are the trap-built Rajmahal hills of western Bengal; the Nallamalai hills near Cuddapah, built of gneissose granite, and the gneissic plateau of Shevaroys and Pachamalai, south-west of Madras.

GLACIERS

The snow-line, *i.e.* the lowest limit of perpetual snow, on the side of the Himalayas facing the plains of India, varies in altitude from about 14,000 feet on the eastern part of the chain to 19,000 feet on the western. On the opposite, Tibetan, side it is about 3000 feet higher, owing to the great desiccation of that region and the absence of moisture in the monsoon winds that have traversed the Himalayas Owing to the height of the snow-line, the mountains of the Lesser Himalayas, whose general elevation is considerably within 12,000 feet, do not reach it, and therefore do not support glaciers at the present day But in some of the ranges, *e.g.* the Pir Panjal, there is clear evidence, in the thick masses of moraines covering their summits and upper slopes, in the striated and polished rock-surfaces, in the presence of numerous erratics, and other evidences of mountain-sculpture by glacier-ice, that these ranges were extensively glaciated at a late geological period, corresponding with the Pleistocene Glacial age of Europe and America.

Glaciers of the Himalayas.

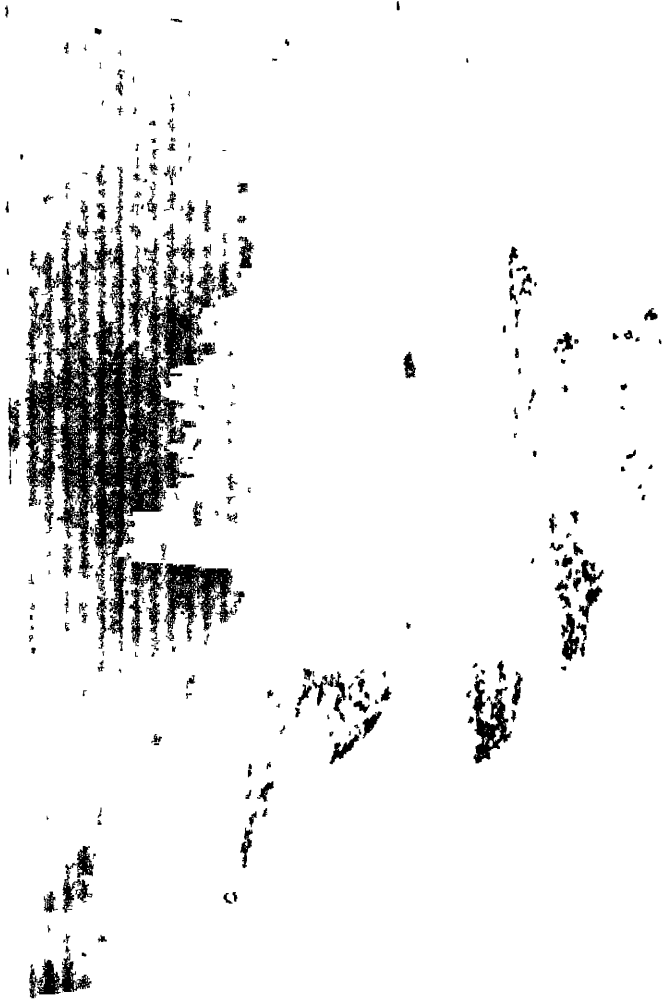
The Great Himalayas, or the innermost line of ranges of high altitudes reaching beyond 20,000 feet, are the enormous

gathering grounds of snow which feed a multitude of glaciers, some of which are among the largest in the world Much attention is being paid now to the scientific study and observation of the Himalayan glaciers, both by the Indian Geological Survey and by scientific explorers of other countries.

Their Size.

In *size* the glaciers vary between wide limits, from those that hardly move beyond the high recesses in which they are formed, to enormous ice-flows rivalling those of the Arctic circle The majority of the Himalayan glaciers are between two to three miles in length, but there are some giant streams of twenty-four miles and upwards, such as the Hispar and the Chogo Lungma of the Hunza valley, Karakoram; while one or two are known to have a length of close upon forty miles, *e.g.* the Báltoro and the Biafo glaciers of the same region The majority of the glaciers are of the type of valley glaciers, but what are known as hanging glaciers are by no means uncommon. As a rule the glaciers descending transversely to the strike of the mountain are shorter, more fluctuating, in their lower limits, and, since the grade is steeper, they descend to such low levels as 7000–8000 feet in some parts of the Kashmir Himalayas Those, on the other hand, that move in longitudinal valleys, parallel to the strike of the mountains, are of a larger volume, less sensitive to alternating temperatures and seasonal variations, and, their gradients being low, they rarely descend to lower levels than 10,000 feet.

Limit of Himalayan glaciers.

The *lowest limit* of descent of the glaciers is not uniform in all parts of the Himalayas While the glaciers of Kinchinjunga in the Sikkim portion hardly move below the level of 13,000 feet altitude, and those of Kumaon and Lahoul to 12,000 feet, the glaciers of the Kashmir Himalayas descend to much lower limits, 8000 feet, not far above villages and fields In several places recent terminal moraines are observed at so low a level as 7000 feet. A very simple cause of this variation has been suggested by T. D. La Touche of the Geological Survey of India. In part it is due to the decrease in latitude, from 36° in the Karakoram to 28° in the Kinchinjunga, and in part to the greater fall of the atmospheric moisture as rain and not as snow in the eastern Himalayas, which rise abruptly from the plains without the intervention of high ranges, than

ALUKTHANG GLACIER.

in the western Himalayas where, though the total precipitation is much less, it all takes place in the form of snow.

Peculiarities of Himalayan glaciers.

One *notable peculiarity* of the Himalayan glaciers, which may be considered as distinctive, is the presence of extensive superficial moraine matter, rock-waste or "dirt", which almost completely covers the upper surface to such an extent that the ice is not visible for long stretches On many of the Kashmir glaciers it is a usual thing for the shepherds to encamp in summer, with their flocks, on the moraines overlying the glacier ice. The englacial and sub-glacial moraine stuff is also present in such quantity as sometimes to choke the ice. The *diurnal motion* of the glaciers, deduced from various observations, is between three and five inches at the sides, and from eight inches to about a foot in the middle. In many parts of the Himalayas there are local traditions, supported in many cases by physical evidences, that there is a slow, general retreat of the glacier-ends; at the lower ends of most of the Himalayan glaciers there are enormous heaps of terminal moraines left behind by the retreating ends of the glaciers. The rate of diminution is variable in the different cases, and no general rule applies to all. In some cases, again, there is an undoubted advance of the glacier ends on their own terminal moraines

In the summer months there is a good deal of melting of the ice on the surface. The water, descending by the crevasses, gives rise to a considerable amount of englacial and sub-glacial drainage. The accumulated drainage forms an englacial river, flowing through a large tunnel, the opening of which at the snout appears as an ice-cave.

Records of past glaciation in the Himalayas.

Large and numerous as are the glaciers and the snow-fields of the Himalayas of the present day, they are but the withered remnants of an older and much more extensive system of ice-flows and snow-fields which once covered Tibet and the Himalayas. As mentioned already, many parts of the Himalayas bear the records of an "Ice Age" in comparatively recent times. Immense accumulations of moraine débris are seen on the tops and sides of many of the ranges of the middle Himalayas, which do not support any glaciers at the present time. Terminal moraines, often covered by grass, are to be

seen before the snouts of existing glaciers at such low elevations as 6000 feet, or even 5000 feet Sometimes there are grassy meadows, pointing to the remains of old silted-up glacial lakes These facts, together with the more doubtful occurrences of what may be termed fluvio-glacial drift at much lower levels in the hills of the Punjab, lead to the inference that this part of India at least if not the Peninsular highlands, experienced a Glacial Age in the Pleistocene period.[1]

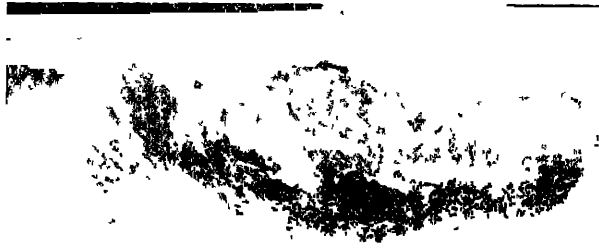
DRAINAGE

The drainage-systems of the two regions, Peninsular and extra-Peninsular India, having had to accommodate themselves to two very widely divergent types of topography, are necessarily very different in their character. In the Peninsula the river-systems, as is obvious, are all of very great antiquity, and consequently, by the ceaseless degradation of ages, their channels have approached the last stage of river-development, viz. the *base-levelling* of a continent The valleys are broad and shallow, characteristic of the regions where vertical erosion has almost ceased, and the lateral erosion of the banks, by winds, rain, and stream, is of greater moment. In consequence of their low gradients the water has but little momentum, except in flood-time, and therefore a low carrying capacity. In normal seasons they are only depositing agents, precipitating their silt in parts of their basins, alluvial banks, estuarine flats, etc., while the streams flow in easy, shallow, meandering valleys. In other words, the rivers of the Peninsula have almost base-levelled their courses, and are now in

[1] The principal glaciers of the Himalayas :

Sikkim—		*Kumaon*—	
Zemu	16 miles	Milam	12 miles.
Kinchinjunga	10 miles	Kedar Nath	9 miles.
		Gangotri	16 miles.
		Kosa	7 miles.
Punjab (Kashmir)—		*Karakoram*—	
Rupal	10 miles.	Biafo	39 miles.
Diyamir	7 miles	Hispar	25 miles.
Sonapani	7 miles.	Báltoro	36 miles.
Rundun	12 miles.	Gasherbrum	24 miles
		Chogo Lungma	24 miles

(Col. S Burrard.)

PLATE II.

SNOUT OF SONA GLACIER FROM SONA.

A Photo by J L Grindlinton (*Geol. Survey of India, Records*, vol. xliv.)

a mature or adult stage of their life-history. Their "curve of erosion" is free from irregularities of most kinds except those caused by late earth-movements, and is more or less uniform from their sources to their mouths [1]

Easterly drainage of the Peninsula.

One very notable peculiarity in the drainage-system of the Peninsula is the pronouncedly easterly trend of its main channels, the Western Ghats, situated so close to the west border of the Peninsula, being the water-shed. The rivers that discharge into the Bay of Bengal have thus their sources, and derive their head waters almost within sight of the Arabian Sea. This feature in a land area of such antiquity as the Peninsula, where a complete hydrographic system has been in existence for a vast length of geologic time, is quite anomalous, and several hypotheses have been put forward to account for it. One supposition regards this fact as an indication that the present Peninsula is the remaining half of a land mass, which had the Ghats very near its centre as its primeval water-shed. This water-shed has persisted, while a vast extension of the country west of it has been submerged underneath the Arabian Sea. Another view, equally probable, is suggested by the exceptional behaviour of the Narbada and the Tapti These rivers discharge their drainage to the west, while all the chief rivers of the country, from Cape Comorin through the Western Ghats and the Aravallis to the Siwalik hills near Hardwar (a long water-shed of 1700 miles), all run to the east. This exceptional circumstance is explained by the supposition that the Narbada and Tapti do not flow in valleys of their own eroding, but have usurped for their channels two fault-planes,

[1] It cannot be said, however, that the channels are wholly free from *all* irregularities, for some of them do show very abrupt irregularities of the nature of *Falls*. Among the best known waterfalls of South India are: the Sivasamudram falls of the Cauvery in Mysore, which have a height of about 300 feet; the Gokak falls of the river of that name in the Belgaum district, which are 180 feet in height, the "Dhurandhar" or the falls of the Narbada at Jabalpur, in which, though the fall is only 30 feet, the volume of water is large. The most impressive and best-known of the waterfalls of India are the Gersoppa falls of the river Sharavati in North Kanara, where the river is precipitated over a ledge of the Western Ghats to a depth of 850 feet in one single fall. The Yonna falls of the Mahableshwar hills descend 600 feet below in one leap while the falls of the Paikara in the Nilgiri hills descend less steeply in a series of five cataracts over the gneissic precipice Indeed, it may be said that such falls are more characteristic of Peninsular than of extra-Peninsular India.

or cracks, running parallel with the Vindhyas. These faults are said to have originated with the bending or "sagging" of the northern part of the Peninsula at the time of the upheaval of the Himalayas as described before. As an accompaniment of the same disturbance, the Peninsular block, south of the cracks, tilted slightly eastwards, causing the eastern drainage of the area.

This peculiarity of the hydrography of the Peninsula is illustrated in the distribution and extent of the alluvial margin on the two coasts. There is but a scanty margin of alluvial deposit on the western coast, except in Gujarat, whereas there is a wide belt of river-borne alluvium on the east coast, in addition to the great deltaic deposits at the mouths of the Mahanadi, Godavari, Kistna, Cauvery, etc.

A further peculiarity of the west coast is the absence of deltaic deposits at the mouths of the streams, even of the large rivers Narbada and Tapti This peculiarity arises from the fact that the force of the currents generated by the monsoon gales and the tides is too great to allow alluvial spits or bars—the skeleton of the deltas—to accumulate On the other hand, the debouchures of these streams are broad deep estuaries daily swept by the recurring tides.

As a contrast to the drainage of Peninsular India, it should be noted that the island of Ceylon has a "radial" drainage, *i.e.* the rivers of the island flow outwards in all directions from its central highlands, as is well seen in any map of Ceylon

The Drainage of the Extra-Peninsula Area.

The Himalayan system of drainage not a *consequent* drainage.

In the extra-Peninsula the drainage system, owing to the mountain-building movement of the Pliocene age, is of much more recent development, and differs radically in its main features from that of the Peninsula. The most important fact to be realised regarding the drainage is that it is not a *consequent* drainage, *i.e.* its formation was not consequent upon the physical features, or the relief, of the country, as we now see them; but there are clear evidences to show that the principal rivers of the area were of an age anterior to them.

In other words, all the great Himalayan rivers are older than the mountains they traverse During the slow process of mountain-formation by the folding, contortion, and upheaval of the rock-beds, the old rivers kept very much to their own channels, although certainly working at an accelerated rate, by reason of the great stimulus imparted to them by the uplift of the region near their source The great momentum acquired by this upheaval was expended in eroding their channels at a faster rate. Thus the elevation of the mountains and the erosion of the valleys proceeded, *pari passu*, and the two processes keeping pace with one another to the end, a mountain-chain emerged, with a completely developed valley-system intersecting it in deep transverse gorges or cañons. These long, deep precipitous gorges of the Himalayas, cutting right through the line of its highest elevations, are the most characteristic features of its geography, and are at once the best-marked results, as they are the clearest proofs, of the inconsequent drainage of this region From the above peculiarities the Himalayan drainage is spoken of as an *Antecedent* drainage, meaning thereby a system of drainage in which the main channels of flow were in existence before the present features of the region were impressed on it

The Himalayan water-shed.

This circumstance of the antecedent drainage also gives an explanation of the much-noted peculiarity of the great Himalayan rivers, that they drain not only the southern slopes of those mountains, but, to a large extent, the northern Tibetan slopes as well, the water-shed of the chain being not along its line of highest peaks, but a great distance to the north of it. This, of course, follows from what we have said in the last paragraph. The drainage of the northern slopes flows for a time in longitudinal valleys, parallel to the mountains, but sooner or later the rivers invariably take an acute bend and descend to the plains of India by cutting across the mountain in the manner already described.

The transverse gorges of the Himalayas.

These transverse gorges of the Himalayas are sometimes thousands of feet in depth from the crest of their bordering precipices to the level of the water at their bottom. The most remarkable example is the Indus valley in Gilgit, where at one place the river flows through a narrow defile, between

enormous precipices nearly 20,000 feet in altitude, while the bed of the valley is only 3000 feet above its level at Haiderabad (the head of its delta) This gives to the gorge the stupendous depth of 17,000 feet, yet the fact that every inch of this chasm is carved by the river is clear from the fact that small patches or "terraces" of river gravel and sand-beds are observed at various elevations above the present bed of the Indus, marking the successive levels of its bed.

[Although there is no doubt, now, regarding the true origin of the transverse gorges of the Himalayas by the process described above, these valleys have given rise to much discussion in the past, it being not admitted by some observers that those deep defiles could have been entirely due to the erosive powers of the streams that now occupy them It was thought by many that originally they were a series of transverse fissures or faults in the mountains which have been subsequently widened by water-action. Another view was that the elevation of the Himalayas dammed back the old rivers and converted them into lakes for the time being The waters of these lakes on overflowing have cut the gorges across the mountains, in the manner of retreating waterfalls

There is no doubt, however, that *some* of these transverse valleys, namely those of the minor rivers, have been produced in a great measure by the process of *head-erosion*, whereby the water-shed receded further and further northwards. It is necessary to admit this because the volume of drainage from the northern slopes, in the early stages of valley-growth, could not have been large enough to give it sufficient erosive energy to keep its valleys open during the successive uplifts of the mountains.]

River-capture or piracy

Many of the Himalayan rivers, in their higher courses, illustrate the phenomena of river-capture or "piracy." This has happened oftentimes through the rapid head-erosion of their main transverse streams, capturing or "beheading" successively the secondary laterals belonging to the Tibetan drainage-system on the northern slopes of the Himalayas. The best examples of river-capture are furnished by the Ganges, the Tista and the Sind[1] river in Kashmir.

"Hanging valleys" of Sikkim

Some of the valleys of the Sikkim Himalayas furnish instructive examples of "hanging valleys," that is, side-valleys or tributaries whose level is some thousands of feet higher than the level of the main stream into which they discharge. These hanging valleys have in the majority of instances

[1] Oldham, *Rec G.S.I.* vol. xxxi. pt 3, 1904

originated by the above process of rapid head-erosion and capture of the lateral streams on the opposite slope A well-known example is that of a former tributary of the Tista river of Sikkim, discharging its waters by precipitous cascades into the Rathong Chu, which is flowing nearly 2000 feet below its bed Prof. Garwood, in describing this phenomenon, suggests that the difference in level between the hanging side-valley and the main river is due not wholly to the more active erosion of the latter, but also to the recent occupation of the hanging valley by glaciers, which have protected it from the effects of river-erosion.

LAKES

Lakes play very little part in the drainage system of India. Even in the mountainous regions of the extra-Peninsula, particularly in the Himalayas, where one might expect them to be of frequent occurrence, lakes of any notable size are very few.

Lakes of Tibet, Kumaon and Kashmir.

The principal lakes of the extra-Peninsula are those of Tibet (including the sacred Mānsarovar and Rakas Tal, the reputed source of the Indus, Sutlej, and Ganges of Hindu traditions); the lakes of Sikkim, Yamdok Cho, 45 miles in circumference, Chamtodong, 54 miles, the group of small Kumaon lakes (the Nainital, Bhim Tal, etc.); and the few lakes of Kashmir, of which the Pangkong, Tsomorri, the Salt Lake, the Wular and Dal are the best-known surviving instances There is some controversy with regard to the origin of the numerous lakes of Tibet, which occupy thousands of square miles of its surface. Many are regarded as due to the damming up of the main river-valleys by the alluvial fans of tributary side-valleys (F. Drew)[1]; some are regarded as due to an elevation of a portion of the river-bed at a rate faster than the erosion of the stream (Oldham)[2]; while some are regarded as true erosion-hollows, scooped out by glaciers—rock-basins.[3] The origin of the Kumaon lakes is yet uncertain; while a few may be due to differential earth-movements

[1] *Jammu and Kashmir Territories* (London), 1875

[2] *Rec G.S.I.* vol. xxi. pt. 3, 1888

[3] Huntington, *Journal of Geology*, vol. xiv. 1906, p 599.

like faulting, others may have been produced by landslips, glaciers, etc The small fresh-water lakes of Kashmir are ascribed a very simple origin by Dr Oldham. They are regarded by him as mere inundated hollows in the alluvium of the Jhelum, like the *jhils* of the Ganges delta.

Salinity of the Tibetan lakes.

The lakes of Tibet exhibit two interesting peculiarities, viz. the growing salinity of their waters and their pronounced diminution of volume, since late geological times The former circumstance is explained by the fact that the whole lake-area of Tibet possesses no outlet for drainage The interrupted and restricted inland drainage, therefore, accumulates in these basins and depressions of the surface where solar evaporation is very active, concentrating the chemically dissolved substances in the waters All degrees of salinity are met with, from the drinkable waters of some lakes to those of others saturated with common salt, sodium carbonate, and borax.

Their desiccation.

The desiccation of the Tibetan lakes is a phenomenon clearly observed by all travellers in that region Old high-level terraces and sand and gravel beaches, 200 to 300 feet above the present level of their waters, are seen surrounding almost all the basins, and point to a period comparatively recent in geological history when the water stood at these high levels. This diminution of the volume of the water, in some cases amounting to a total extinction of the lakes, is one of the signs of the increasing dryness or desiccation of the region north of the Himalayas following a great change in its climate This is attributed in some measure to the disappearance of the glaciers of the Ice Age, and to the uplift of the Himalayas to their present great elevation, which has cut off Tibet from the monsoonic currents from the sea

Besides the few small fresh-water lakes of the Peninsula, two occurrences there are of importance because of some exceptional circumstances connected with their origin and their present peculiarities. The one is the group of salt-lakes of Rajputana, the other is the volcanic hollow or crater-lake of Lonar in the Deccan

The Sambhar salt-lake.

Of the four or five salt-lakes of Rajputana, the Sambhar lake is the most important. It has an area of ninety square miles when full during the monsoon, at which period the depth

of the water is about four feet. For the rest of the year it is dry, the surface being encrusted by a white saliferous silt. The cause of the salinity of the lake was ascribed to various circumstances, to former connection with the Gulf of Cambay, to brine-springs, to chemical dissolution from the surrounding country, etc But lately Sir T. H Holland and Dr Christie[1] have discovered quite a different cause of its origin. They have proved that the salt of the Sambhar and of the other salt-lakes of Rajputana is wind-borne; it is derived partly from the evaporation of the sea-spray from the coasts and partly from the desiccated surface of the Rann of Cutch, from which sources the dried salt-particles are carried inland by the prevalent winds The persistent south-west monsoons which blow through Rajputana for half the year, carry a large quantity of saline mud and salt-particles from the above sites, which is dropped when the velocity of the winds decreases. When once dropped, wind-action is not powerful enough to lift up the particles again The occasional rainfall of these parts gathers in this salt and accumulates it in the lake-hollows which receive the drainage of the small streams. It is calculated by these authors, after a series of experiments, that some 130,000 tons of saline matter is annually borne by the winds in this manner to Rajputana during the hot weather months.

The Lonar lake.

The Lonar lake is a deep crater-like hollow or basin in the basalt-plateau of the Deccan, in the district of Buldana. The depression is about 300 feet in depth and about a mile in diameter. It is surrounded on all sides by a rim formed of blocks of basalts. The depression contains at the bottom a shallow lake of saline water. The chief constituent of the salt water is sodium carbonate, together with a small quantity of sodium chloride. These salts are thought to have been derived from the surrounding trap country by the chemical solution of the disintegrated product of the traps and subsequent concentration

The origin of the Lonar lake hollow has been ascribed to a volcanic explosion unaccompanied by any lava eruption. This is one of the rare instances of volcanic phenomena in

[1] *Rec. G.S.I.* vol. xxxviii pt. 2, 1909

India within recent times. On this view the lake-hollow is an explosion-crater or a *caldera*. Another explanation has been given lately,[1] which explains the hollow as due to an engulfment or subsidence produced by the sinking of the surface between a circular fracture or fractures, into a cavern emptied by the escape of lava or volcanic vapours into the surrounding places.

THE COASTS

The coasts of India are comparatively regular and uniform, there being but few creeks, inlets, or promontories of any magnitude. It is only on the Malabar coast that there are seen a number of lakes, lagoons or back-waters which form a noteworthy feature of that coast These back-waters, *e g* the *Kayals* of Travancore, are shallow lagoons or inlets of the sea lying parallel to the coast-line. They form an important physical as well as economic feature of the Malabar coast, affording facilities for inland water-communication The silts brought by the recurring monsoon floods support large forests and plantations along their shores At some places, especially along the tidal estuaries or salt-marshes, there are the remarkable mangrove-swamps lining the coasts. The whole sea-board is surrounded by a narrow submarine ledge or platform, the "plain of marine denudation," where the sea is very shallow, the soundings being much less than 100 fathoms. This shelf is of greater breadth on the Malabar coast and on the Arakan coast than on the Coromandel coast. From these low shelving plains the sea-bed gradually deepens, both towards the Bay of Bengal and the Arabian Sea, up to a mean depth of 2000 fathoms in the former and 3000 fathoms in the latter sea. The seas are not of any great geological antiquity, both having originated in the earth-movements of the early Tertiary times, as bays or arms of the Indian Ocean overspreading areas of a large southern continent (Gondwanaland), which, in the Mesozoic ages, connected India with Africa and with Australia. The islands of the seas are continental islands, with the exception of the group of coral

[1] La Touche, *Rec G S I* vol. xli pt 4, 1912.

islands, the Maldives and the Laccadives, which are atolls or barrier-reefs, reared on shallow submarine banks, the unsubmerged, elevated points of the ancient continent. Barren Island and Narcondam are volcanic islands east of the Andamans. The low level and smooth contours of the tract of country which lies in front of the S.E. coast below the Mahanadi suggest that it was a submarine plain at a comparatively late date which has emerged from the waters. Behind this coastal belt are the gneissic highlands of the mainland—the Eastern Ghats—which are marked by a more varied relief and rugged topography. Between these two lies the old shore-line.

VOLCANOES

There are no living or active volcanoes anywhere in the Indian region. The Malay branch of the line of living volcanoes—the Sunda chain—if prolonged to the north, would

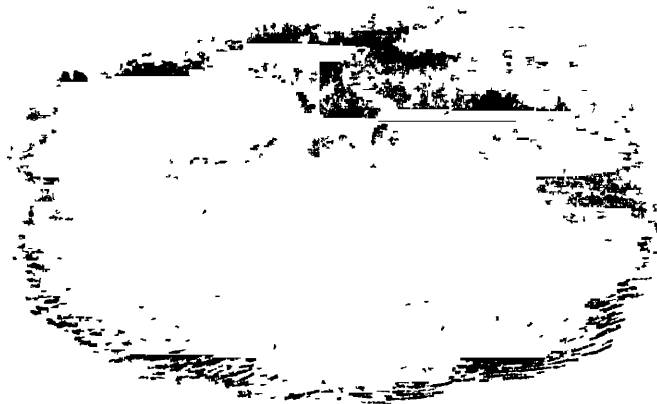



FIG. 2.—The Volcano of Barren Island in the Bay of Bengal. (H. F. Blanford, 1908.)

connect a few dormant or extinct volcanoes belonging to this region. Of these the most important is the now dormant volcano of Barren Island (Fig. 2) in the Bay of Bengal, to the east of the Andaman Islands, 12° 15′ N. lat.; 93° 54′ E. long. What is now seen of it is a mere truncated remnant

Barren Island volcano.

of a once much larger cone—its *basal wreck* or caldera. It consists of an outer amphitheatre, about two miles in diameter, breached at one or two places, the remains of the old cone, surrounding an inner, much smaller, but symmetrical cone, composed of regularly bedded lava-sheets of comparatively recent eruption. At the summit of this newer cone is a crater, about 1000 feet above the level of the sea. But the part of the volcano seen above the waters is quite an insignificant part of its whole volume. The base of the cone lies some thousands of feet below the surface of the sea.

The last time it was observed to be in eruption was in 1789, since then no authentic observation is recorded of its eruptions, though it was reported to be active in 1803. Since then it has been dormant, but sublimations of sulphur on the walls of the crater point to a mild solfataric phase into which the volcano has declined Mr F R. Mallet, of the Geological Survey of India, has given a complete account of Barren Island in *Memoir*, vol. xxi. pt 4, 1885 [1]

Narcondam.

Another volcano, along the same line, is that of the island of Narcondam, a craterless volcano composed wholly of andesitic lavas. From the amount of denudation that the cone has undergone it appears to be an old extinct volcano. The third example is the volcano of Puppa, a large centrally situated cone composed of trachytes, ashes, and volcanic breccia, situated about fifty miles north-west of the oil-field of Yenangyaung. This is also extinct now, the cone is much weathered, and the crater is only preserved in part. From the fact that some volcanic matter is found interstratified in the surrounding strata belonging to the Irrawaddy group, it seems that this volcano must have been in an active condition as far back as the Pliocene. A fourth extinct volcano is situated on the same line, north of Puppa, near Momien It is named Hawshuenshan

Puppa.

Haw-shuenshan

[1] Captain Blair has described an eruption of Barren Island in 1795. Glowing cinders and volcanic blocks up to some tons in weight were discharged from the crater at the top of the new cone, which was also ejecting enormous clouds of gases and vapours. Another observer, in 1803, witnessed a series of explosions at the crater at intervals of every ten minutes, throwing out masses of dense black gases and vapours with great violence to considerable heights.

MUD VOLCANO ONE OF THE LARGEST MINBU, BURMA

Photo E H Pascoe (Geol. Survey of India, vol xl)

One more volcano, within the Indian Empire, but far on its western border, is the large extinct volcano of Koh-i-Sultan in the Nushki desert of western Baluchistan.

Koh-i-Sultan.

Among the volcanic phenomena of recent age must also be included the crateriform lake of Lonar, noticed in the preceding section. Whatever may be its exact origin, it is ultimately connected with volcanic action.

Mud-volcanoes.

Mud-Volcanoes —We must here consider a curious phenomenon —what was once regarded as a decadent phase of volcanic action, but which has no connection whatever with vulcanicity as explained by Pascoe.[1] On the Arakan coast of Burma and also at some places on the Irrawaddy there occur groups of small cones of mud ejected by outbursts of gas from small vents or holes in the ground. They are known as Mud-volcanoes or salses.[2] Mud-volcanoes occur chiefly in the Ramri and Chedubba islands on the Arakan coast. The majority of these are small conical mounds of twenty or thirty feet, composed of earth which is continually being ejected from the small holes—"craters" at the top. There is usually some saline water discharged, with a small quantity of petroleum. The most common gas is marsh-gas.

The mud-volcanoes belong to two types: in the one, which is usually non-paroxysmal, mud alone is thrown out, the mud being merely disintegrated shale; in the other, which shows a greater activity, fragments of the country rock also are thrown out with some degree of violence, accompanied sometimes with flames, due to the ignition of the hydrocarbons. There is, however, no heat in these eruptions. All the ejecta are at the temperature of the air, the ignition being only due to friction, and not to the internal heat of the earth.

It is now generally recognised that the gases which are the prime cause of these eruptions have had the same origin as the petroleum deposits which are so largely found in the Miocene rocks of Burma (Pegu system). The connection of petroleum with mud-volcanoes is thus commented on by Pascoe: The so-called "Mud-Volcanoes" are entirely due to the escape of gas, the mud and rock-fragments being purely accidental accompaniments, and constitute a perfectly normal part of the hydro-carbon occurrences in the "oil-belts." There is every gradation between a small insignificant oil or gas seapage and the conspicuous mounds or cones like those on the Arakan coast, whose terrific outbursts afford some excuse for their having been mistakenly attributed

[1] Pascoe, *Mem. G.S I.* vol. xl. pt. 1 (1912), pp. 211-215.

[2] Coggin Brown, *Rec. G.S.I.* vol. xxxvii. pt. 3, 1909.

to volcanic disturbance" If this is the origin, the mud-volcanoes are volcanoes only in name, and their second name "salses" is more expressive of their true nature.]

Along the Mekran coast of Baluchistan there also exist a few mud-volcanoes, situated on the crests of anticlinal folds of Miocene sandstones Here the eruptions are never paroxysmal, and the mounds, therefore, like the true volcanoes, have a chance of attaining to greater height. Some of them are nearly 300 feet high

EARTHQUAKES

The earthquake zone of India.

Few earthquakes have visited the Peninsula since historic times ; but those that have shaken the extra-Peninsula form a long catalogue.[1] It is a well-authenticated generalisation that the majority of the Indian earthquakes have originated from the great plains of India, or from their peripheral tracts

Of the great Indian earthquakes recorded in history the best-known are · Delhi, 1720, Calcutta, 1737, Eastern Bengal and the Arakan coast, 1762 ; Cutch, 1819 ; Kashmir and Bengal, 1885 ; Assam, 1897, and Kangra, 1905, all of these, in the site of their origin, agree with the above statement

The area noted above is the zone of weakness and strain implied by the severe crumpling of the rock-beds in the elevation of the Himalayas within very recent times, which has, therefore, not yet attained stability or quiescence. It falls within the great earthquake belt which traverses the earth east to west.

The Kangra earthquake was a subject of special investigation by the Geological Survey of India, and Middlemiss has given a detailed account of this investigation in *Mem.* vol xxxviii 1910

The Kangra earthquake.

[The earthquake took place on the early morning of the 4th April, 1905. The shock, which was felt over the whole of India north of the Tapti valley, was characterised by exceptional violence and destructiveness along two linear tracts between Kangra and Kulu, and between Mussoorie and Dehra Dun. These were the *epifocal* tracts. The destruction grew less and less in severity as the

[1] Oldham, "List of Indian Earthquakes," *Mem. G.S.I.* vol. xix pt. 3, 1883.

distance from them increased, but the area that was perceptibly shaken, and which is encompassed by the *isoseist* of Intensity II of the Rossi-Forel scale, comprised such distant places as Afghanistan, Quetta, Sind, Gujarat, the Tapti valley, Puri and the Ganges delta The *centra* or the foci of the original concussion, or blow, were linear, corresponding to the two linear epicentra, Kangra-Kulu and Mussoorie-Dehra Dun, or areas which were directly overhead and in which the vibrations were vertical, up and down The *isoseists*, or curves of equal intensity, were hence ellipsoidal.

The *velocity* of the quake was difficult to judge, because of the absence of any accurate time-records at the different outlying places But from a number of observations, the mean is deduced to be nearly 1 92 miles per second as the velocity of the earth-wave.

Middlemiss does not support the view that earthquakes of great severity originate near the surface in a complex network of faults and fractures He ascribes to the present earthquake a deep-seated origin, and calculates, from Dutton's formula for deducing the depth of focus, a depth varying from 21 to 40 miles

The main-shock was sudden, with only a few premonitory warnings, but the *after-shocks*, of moderate to slight intensity, which succeeded it for weeks and months, were several hundred in number. During the whole of 1906 the number of after-shocks was from ten to thirty a month In 1907 they decreased in number, but scarcely in intensity. In the succeeding years the number of shocks grew fewer till they gradually disappeared

The *geological effects* of the earthquake were not very marked. There were the usual disturbances of streams, springs, and canals; a number of landslips and rock-falls took place, also a few slight alterations in the level of some stations and hill-tops (*e g* Dehra Dun and the Siwalik hills showed a rise of about a foot relatively to Mussoorie) No true fissures of dislocations were, however, seen. In the above respects this earthquake offers a marked contrast to the Assam quake of 12th June, 1897, where the geological results were of a more serious description and more permanent in their effect Numerous rock-fissures, miles in length, were opened, producing dislocations, or relative displacements, of several feet at the surface, and causing many and serious interruptions in the drainage-courses The river Cachar was intersected by some of these fissures, which produced in it a number of waterfalls and lakes

With regard to the *cause* of the earthquake, there is no doubt that it was a tectonic quake Middlemiss is of opinion that it was due to a slipping of one of the walls or change of strain of a fault parallel to the "Main Boundary Fault" of the outer Himalayas at two points Just where the two epicentra lie are two very well-defined "bays" or inpushings of the younger Tertiary rocks into the older rocks of the Himalayas, showing much packing

and folding of the strata Relief was sought from this compression by a slight sinking of one side of the fault.]

Local Alterations of Level.

Elevation of the Peninsular tableland.

Few hypogene disturbances have interfered with the stability of the Peninsula as a continental land-mass for an immense length of geological time, but there have been a few minor movements of secular upheaval and depression along the coasts within past as well as recent times Of these, the most important is that connected with the slight but appreciable elevation of the Peninsula, exposing portions of the plain of marine denudation as a shelf or platform round its coasts, the west as well as the east Raised beaches are found at altitudes varying from 100 to 200 feet, while marine shells are found at several places some distance inland, and at a height far above the level of the tides. The steep face of the Sahyadri mountains, looking like a line of sea-cliffs, and their approximate parallelism to the coast lead to the inference that the escarpment is a result of a recent elevation of the Ghats from the sea and subsequent sea-action modified by subaerial denudation Marine estuarine deposits of post-Tertiary age are met with on a large scale towards the southern extremity of the Peninsula

Local alterations

Besides these evidences of a rather prominent uplift of the Peninsula, there are also proofs of minor, more local alterations of level, both of elevation and depression, within sub-recent and pre-historic times The existence of beds of lignite and peat in the Ganges delta, the peat deposits below the surface near Pondicherry, the submerged forest discovered on the eastern coast of the island of Bombay, etc, are proofs of slow movements of depression. Evidences of upheaval are furnished by the exposure of some coral reefs along the coasts, low-level raised beaches on various parts of the Ghats, and recent marine accumulations above the present level of the sea.

Submerged forest of Bombay

The submerged forest of Bombay is nearly 12 feet below low-water mark and 30 feet below high-water; here a number of tree-stumps are seen with their roots *in situ*, embedded in the old soil [1] On the Tinnevelli coast a similar

[1] *Rec G.S I* vol xi pt 4, 1878.

forest or fragment of the old land surface, half an acre in extent, is seen slightly below high-water mark. Further evidence to the same effect is supplied by the thick bed of lignite found at Pondicherry, 240 feet below ground level. About twenty miles from the coast of Mekran the sea deepens suddenly to a great hollow. This is thought to be due to the submergence of a cliff formerly lying on the coast. The recent subsidence, in 1819, of the western border of the Rann of Cutch under the sea, accompanied with the elevation of a large tract of land (the *Allah Bund*), is the most striking event of its kind recorded in India, and was witnessed by the whole population of the country. Here an extent of the country, some 2000 square miles in area, was suddenly depressed to a depth of from 12 to 15 feet, and the whole tract converted into an inland sea. The fort of Sindree, which stood on the shores, the scene of many a battle recorded in history, was also submerged underneath the waters, and only a single turret of that fort remained, for many years, exposed above the sea. As an accompaniment of the same movements, another area, about 600 square miles, was simultaneously elevated several feet above the plains, into a mound which was appropriately designated by the people the "Allah Bund" (built of God).

Alterations of level in Cutch

Even within historic times the Rann of Cutch was a gulf of the sea, with surrounding coast towns, a few recognisable relics of which yet exist. The gulf was gradually silted up, a process aided no doubt by a slow elevation of its floor, and eventually converted into a low-lying tract of land, which at the present day is alternately a dry saline desert for a part of the year, and a shallow swamp for the other part.

The branching *fjords*, or deep narrow inlets of the sea, in the Andaman and Nicobar islands in the Bay of Bengal, point to a submergence of these islands within late geological times, by which its inland valleys were "drowned" in their lower parts. In some of the creeks of Kathiawar near Porbander, for example, oyster-shells were found at several places and at levels much above the present height of the tides, while barnacles and *serpulae* were found at levels not now reached by the highest tides. In Sind a number of oyster-banks have

been seen several feet above high-water mark Oyster-shells discovered lately at Calcutta likewise point to a slight local rise of the eastern coast

Himalayas yet in a state of tension.

It is the belief of some geologists that appreciable changes of level have recently taken place, and are still taking place, in the Himalayas, and that although the loftiest mountains of the world, they have not yet attained to their maximum elevation, but are still rising. That alterations of level have lately taken place is clear from a number of circumstances Many of the rivers bear incontrovertible proofs of recent rejuvenation, due to the uplift of their water-shed Another fact, suggesting the same inference, is the frequency and violence of earthquakes on the Himalayas and on the plains lying at their foot. By far the largest number of disastrous Indian earthquakes have occurred, as already remarked, along these tracts. They indicate that the strata under the Himalayas are in a state of tension, and are not yet settled down to their equilibrium plane. Relief is therefore sought by the subsidence of some tracts and the elevation of others.

DENUDATION

Among the physical features of India, a brief notice of the various denudational processes in operation in the country at the present time must be included. Inasmuch as climate is an important determining factor in the denudation of a region, the peculiar features which the climate of India possesses require consideration. The most unique feature in the meteorology of India is the monsoonic alternations of wet and dry weather. The division of the year into a wet half, from May to October, the period of the moist, vapour-laden winds from the south-west (from the Bay of Bengal and the Arabian Sea) towards Tibet and the heated tracts to the north, and the dry half, from November to April, the period of the retreating dry winds blowing from the north-east, has a preponderating influence on the character and rate of subaerial denudation of the surface of the country.

Monsoonic alternations

The intensity of the influence exercised by this dominating

factor in the atmospheric circulation of the Indian region will be realised when the extent and thickness of the peculiar surface formation, *laterite*, is considered. Laterite is a form of regolith highly peculiar to India, which covers the whole expanse of the Peninsula from the Ganges valley to Cape Comorin, it is believed by most authorities to have resulted from the subaerial alteration of its surface rocks under the alternately dry and humid (*i.e* monsoonic) weather of India. Another characteristic product of weathering of the surface rocks *in situ* in the Peninsula is the Black Soil (*regur*),[1] which covers also large tracts of country in South India. The *Reh* efflorescences of the plains of North India and the formation of *nitre* in some soils should also be noted in this connection.[2]

Lateritic regolith.

If this factor is excluded, the general atmospheric weathering or denudation of India is that characteristic of the tropical or sub-tropical zone of the earth This, however, is a very general statement of the case Within the borders of India every variety of climate is met with, from the torrid heat of the vast inland plains of the Punjab and North-east Baluchistan and upland plateaus (like Ladakh) to the Arctic cold of the higher ranges of the Himalayas, and from the reeking tropical forests of the coastal tracts of the Peninsula to the desertic regions of Sind, Punjab and Rajputana. Rock *disintegration* is the predominant process in the one area, rock *decomposition* in the other The student can easily imagine the intensity of frost-action in the Himalayan highlands and the comparative mildness of the other agents of erosion in that area, such as rapid alternations of heat and cold, chemical action, etc, and the vigorous chemical and mechanical erosion of the tropical monsoon-swept parts of the Peninsula, the denudation of some parts of which partakes of the character of that prevailing in the equatorial belt of the earth.

General character of denudation sub-tropical.

In the desert tracts of Rajputana, Sind and Baluchistan, mechanical disintegration due to the prevalent drought with its great extremes of heat and cold, the powerful insolation and wind-action, is dominant, to the exclusion of other agents of change In this belt the action of the powerful summer-winds and dust-storms which blow for about two months preceding the summer, must result in the transport of vast quantities of fine detritus, the prolonged accumulation of which has been the cause of the wide-spread loëss deposits of N W. India Rajputana affords a noteworthy example of the evolution of desert topography within comparatively recent geological times. This change has been brought about by the great dryness that has overcome this region since Pleistocene times, leading to the intensity of aeolian action on its surface.

Desert-erosion in Rajputana.

[1] The subject of soils of India is treated in Chap. XXVI. p. 332.

[2] Chapter XXVI.

Peculiarity of river-erosion in India.

The Indian rivers accomplish an incredible amount of erosion during the wet half of the year, transporting to the sea an enormous load of silt, in swollen muddy streams A stream in flood-time accomplishes a hundred times the work it performs in the normal seasons. If the same amount of rainfall, therefore, were evenly distributed throughout the year, the denudation would be far less in amount.

Their floods.

The Himalayan streams and rivers are specially noted for their floods of extraordinary severity in the spring and monsoon seasons. Several of the Indus floods are noted in history, the most recent and best remembered being those of 1841 and 1858. Drew [1] gives a graphic account of the 1841 flood, when, after a period of unusual low level of the waters in the winter and spring of that year, the river, all of a sudden, descended in a black mighty torrent that in a few minutes tore and swept away everything in its course, including a whole Sikh army that had encamped on its banks below Attock with its tents, baggage and artillery. The cause of this flood is attributed to a landslip in the narrow, gorge-like part of the river in Gilgit, which blocked up the water and converted the basin of the river above it into a lake thirty-five miles long and some hundreds of feet in depth. The sudden bursting of the barrier by the constantly increasing pressure of the water on it after the spring thaw is supposed to have caused the inundation.

Many mountain channels are known to have been dammed back by the precipitation of a whole hillside across them. In 1893, in Garhwal, a tributary of the Ganges, the Alaknanda, was similarly blocked by the fall of a hillside, and was converted into a lake at Gohna. The lake spread in extent and steadily rose in height for several months, till the waters ultimately surmounted the obstacle, and caused a severe flood by the sudden draining of a large part of the lake.[2]

The increased volume of water, combined with the high velocity of the rivers in flood-time, multiplies their erosive and transporting power to an inconceivable extent, and boulders and blocks, several feet in diameter, are rolled along their bed, and carried in this manner to distances of fifty or even a hundred miles from their source, causing much injury to the banks and wear and tear to the beds of the channels.

Late Changes in the Drainage Systems of North India.

Many and great have been the changes in the chief drainage lines of North India since late Tertiary times [3]—changes in fact

[1] *Jammu and Kashmir Territories*, London, 1875.

[2] *Rec. G.S.I.* vol. xxvii. pt. 2, 1894

[3] E H. Pascoe, "The Indobrahm," *Quart. Journ. Geol. Soc.*, vol. lxxv. pp 138-155 (1919); G E. Pilgrim, "The Siwalik River," *Journ. Asiat. Soc. Beng*, vol. xv. (New Series), pp. 81-99 (1919).

which have produced a complete reversal of the directions of flow of the chief rivers of North India. The formation of the Siwalik system of deposits is now ascribed to the flood-plain deposits of a great north-west-flowing river lying south of and parallel with the Himalayan chain from Assam to the furthest north-west corner of the Punjab, and then flowing southwards to meet the gradually receding Miocene sea of Sind and Punjab (the "Indobrahm" of Pascoe) This old river is, indeed, believed to have come into existence by gradual replacement of the retreating gulf of the Eocene sea, in which the Nummulitic rocks of the Outer Himalayas were formed, as it was pushed back from Assam by the Himalayan movements. The formation of a large section of the sub-montane Siwalik deposits is the work of this river during the interval from Middle Miocene to Pliocene, until the final elevation of the Himalayas brought about a dismemberment of the great river-system into three subsidiary river-systems, viz.: (1) the present Indus from North-west Punjab; (2) the five great Punjab tributaries of the Indus, and (3) the rivers belonging to the Ganges system, which finally took a south-easterly course In this breaking up and reversal of the old drainage lines Dr E H. Pascoe assigns the chief share to processes of river-capture by the head-erosion of the tributaries.

The Himalayas being a zone of recent folding and fracture, their disintegration by subaerial erosion is relatively rapid. The plains of India and the Ganges delta are a fair measure of the amount of matter worn down from a section of the Himalayas since the Pliocene period. Land-slides, soil-creep, breaking off of enormous blocks from the mountain-tops are phenomena familiar to visitors to these mountains. The denudation in the dense forests of the hill-slopes in the Eastern Himalayas recalls that of the tropical lands.

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CHAPTER II

STRATIGRAPHY OF INDIA—INTRODUCTORY

Correlation of Indian formations to those of the world.

An outstanding difficulty in the study of the geology of India is the difficulty of correlating accurately the various Indian systems and series of rocks with the different divisions of the European stratigraphical scale which is accepted as the standard for the world. The difficulty becomes much greater when there is a total absence of any kind of fossil evidence, as in the enormous rock-systems of the Peninsula, in which case the determination of the geological horizon is left to the more or less arbitrary and unreliable tests of lithological composition, structure, and the degree of metamorphism acquired by the rocks These tests are admittedly unsatisfactory, but they are the only ones available for fixing the homology of the vast pre-Cambrian formations of the Peninsula, which form such an important feature of the pre-Palaeozoic geology of India.

There is no question, of course, of establishing any absolute contemporaneity between the rock-systems of India and those of Europe, because neither lithological correspondence nor even identity of fossils is proof of the synchronous origin of two rock-areas so far apart Biological facts prove that the evolution of life has not progressed uniformly all over the globe in the past, but that in different geographical provinces the succession of life-forms has been marked by widely varying rates of evolution due to physical differences existing between them, and that the process of distribution of species from the centre of their origin is very slow and variable. The idea, therefore, of contemporaneity is not to be entertained in geological deposits of two distant areas, even when there is a perfect similarity in their fossil contents

What is essential is, that the rock-records of India, discovered

in the various parts of the country, should be arranged in the order of their superposition, *i.e.* in a chronological sequence They should be classified with the help of local breaks in their sequence, or by the evidence of their organic remains, and named according to some local terminology. The different outcrops should then be correlated among themselves. The last and the most important step is to correlate these, on the evidence of their contained fossils, or failing that, on lithological grounds, to some equivalent division or divisions of the standard scale of stratigraphy worked out from the fossiliferous rock-records of the world.

In illustration of the above it may be remarked that the Carboniferous system of Europe is characterised by the presence of certain types of fossils and by the absence of others. If in any part of India a series of strata are found, containing a suite of organisms in which many of the *genera* and a few of the *species* can be recognised as identical with the above, then the series of strata thus marked off is correlated with the Carboniferous system of Europe, though on account of local peculiarities and variations, the system is often designated by a local name It is not of much significance whether they were or were not deposited simultaneously, so long as they point to the same epoch in the history of life upon the globe, and since the history of the development of life upon the earth, in other words, the order of appearance of the successive life-forms, has been proved to be broadly uniform in all parts of the earth, there is some unity between these two rock-groups. As a substitute for geological synchronism Prof Huxley introduced the term *Homotaxis*, meaning "Similarity of arrangement," and implying a corresponding position in the geological series. The *fauna* and *flora* of the Jurassic system of Europe are considered homotaxial with those of some series of deposits in different parts of India, though it is quite probable that in actual age any of these may have been contemporaneous with the end of the Triassic deposits in one part of the world or with the beginning of the Cretaceous in another.

The different "facies" of Indian formations.

It often happens that one and the same geological formation in the different districts is composed of different types of deposits, *e.g.* in one district it is composed wholly of massive

limestones, and in another of clays and sandstones These divergent types of deposits are spoken of as belonging to different *facies, e g.* a calcareous facies, argillaceous facies, arenaceous facies, etc. There may also be different facies of fauna, just as much as facies of rock-deposits, and the facies is then distinguished after the chief element or character of its fauna, *e.g.* coralline facies, littoral facies, etc. Such is often the case with the rock-formations of India. From the vastness of its area and the prevalence of different physical conditions at the various centres of sedimentation, rocks of the same system or age are represented by two or more widely different facies, one coastal, another deep-water, a third terrestrial, and sometimes even a fourth, volcanic. The most conspicuous example of this is the Gondwana system of the Peninsula and its homotaxial equivalents. The former is an immense system of fresh-water and subaerially deposited rocks, ranging in age from Upper Carboniferous to Upper Jurassic, whose fossils are ferns and conifers, fishes and reptiles. Rocks of the same age, in the Himalayas, are marine limestones and calcareous shales of great thickness, and containing deep-sea organisms like *Lamellibranchs, Cephalopods, Crinoids,* etc., from the testimony of which they are grouped into Upper Carboniferous, Permian, Triassic and Jurassic systems. In the Salt-Range these same systems often exhibit a coastal facies of deposits like clays and sandstones, with littoral organisms, alternating with limestones.

In this connection it must be clearly recognised how these deposits, which are homotaxial, and more or less the time-equivalents of one another, should come to differ in their fossil contents. The reason is obvious For not only are marine organisms widely different from land animals and plants, but the littoral species that inhabit the sandy or muddy bottoms of the coasts are different from those pelagic and abysmal organisms that find a congenial habitat in the clearer waters of the sea and at great distances from land. Again, the animal life of the seas of the past ages was not uniform, but it was distributed according to much the same laws as those that govern the distribution of the marine biological provinces

of to-day It thus arises that the fossils present in a series of deposits are not a *function* of the period only when the deposits were laid down, but, as Lyell says, are a "function of three variables," viz. (1) the geological period at which the rocks were formed, (2) the zoological or botanical provinces in which the locality was situated, and (3) the physical conditions prevalent at the time, *e.g.* depth and character of water, climate, character of the sea-bottom, etc.

The chief geological provinces of India.

The following are the important localities in the country, besides some areas of the Peninsula, wherein the marine fossiliferous facies of the Indian formations are more or less typically developed :

1. The Salt-Range.

[This range of mountains is a widely explored region of India. It was one of the earliest parts of India to attract the notice of the geologists, both on account of its easily accessible position as well as for the conspicuous manner in which most of the geological systems are displayed in its precipices and defiles Over and above its stratigraphic and palaeontological results, the Salt-Range illustrates a number of phenomena of dynamical and tectonic geology.]

2. The Himalayas.

[As mentioned in the first chapter, a broad zone of sedimentary strata lies to the north of the Himalayas, behind its central axis, occupying a large part of Tibet. This is known as the Tibetan zone of the Himalayas. This zone of marine sediments contains one of the most perfect developments of the geological record seen in the world, comprising in it all the periods of earth-history from the Cambrian to the Eocene. It is almost certain that this belt of sediments extends the whole length of the Himalayan chain, from Hazara and Kashmir to the furthest eastern extremity ; but so far only two portions of it have been surveyed in some detail, the one the north-west portion—the Kashmir Himalayas—and the other the mountains of the Central Himalayas north-east of the Simla region, especially the Spiti valley, and the northern parts of Kumaon and Garhwal.]

(i) North-West Himalayas.

[This area includes Hazara, Kashmir, the Pir Panjal, and the ranges of the Outer Himalayas. A very complete sequence of marine Palaeozoic and Mesozoic rocks is met with in the inner zone of the mountains, while a complete sequence of Tertiary development is seen in the outer, Jammu hills. The Kashmir

basin, lying between the Zanskar and the Panjal ranges, contains the most fully developed Palaeozoic system seen in any part of India. For this reason, and because of the easily accessible nature of the formations to parties of students, in a country which climatically forms one of the best parts of India, the geology of Kashmir is treated in a separate chapter at the end of the book.]

(ii) Central Himalayas.

[Many eminent explorers have unravelled the geology of these mountains since the early 'thirties of the last century, and parts of this region, like Spiti, form the classic ground of Indian geology

The Central Himalayas include Spiti, Kumaon and Garhwal provinces. The great plateau of Tibet ends in the northern parts of these areas in a series of gigantic south-facing escarpments, wherein the stratigraphy of the northern or Tibetan zone of the Himalayas, referred to above, is typically displayed. The Spiti basin is the best known for its fossil wealth as well as for the richness of the stratigraphic results it has yielded. The systems of Kashmir are on a north-west continuation of the strike of the Spiti basin.]

3. Sind.

[Sind possesses a highly fossiliferous marine Cretaceous and Tertiary record. The hills of the Sind-Baluchistan frontier contain the best-developed Tertiary sequence, which is recognised as a type for the rest of India.]

4. Rajputana.

[Besides the development of Archaean, Dharwar and Vindhyan systems in the Aravalli range, Western Rajputana contains a few isolated outcrops of marine Mesozoic and early Tertiary strata underneath the Pleistocene desert sand, which has concealed by far the greater part of its solid geology.]

5. Burma and Baluchistan.

[These two countries, at either extremity of the extra-Peninsular area, contain a large section of the stratified marine geological record which helps to fill up the gaps in the Indian sequence. Many of these formations are again highly fossiliferous, and afford good ground for comparison with their Indian congeners. Within the geographical term India is now included all these regions which are regarded as its natural physical extension on its two borders—Afghanistan and Baluchistan on the west and Burma on the east. The student of Indian geology is therefore expected to know of the principal rock-formations of Baluchistan and Burma.]

6. Coastal System of India

[Along the eastern coast of the Peninsula there is a strip of marine sediments of Mesozoic, Tertiary and Quaternary ages, in more or less connected patches—the records of several successive " marine transgressions " on the coasts]

Peninsular India, as must be clear from what we have seen regarding its physical history in the first chapter, is a part of India which contains a most imperfectly developed geological record. The Palaeozoic group is unrepresented but for the fluviatile Permian formations , the Mesozoic era has a fairly full record, but except as regards the Cretaceous it is preponderatingly made up of fluviatile, terrestrial and volcanic accumulations ; while the whole of the Tertiary is unrepresented almost in its entirety.

The student of Indian geology should first familiarise himself with the representatives of the various geological systems that are found in these provinces of India. For this purpose he should thoroughly master the table at the end of the chapter, in which the distribution of the Indian formations in the principal localities is shown, correlated to the principal divisions of the European sequence. He should also, while doing so, consult as often as he can the Geological Map of India,[1] and note the geographical situation, extent and form of the outcrops of the particular series or system he is dealing with. Wherever possible he should note the stratigraphical and structural relations of the various formations from the excellent large-scale maps and sections issued along with the *Records* and *Memoirs* of the Geological Survey of India

But, above all, the student should not commit the mistake of merely trying to memorise the dry summary of facts regarding the " rocks " or " fossils " of a system, or consider that the idea of a geological system is confined to these. These are the dry bones of the science : they must be clothed with flesh and blood, by comparing the processes and actions which prevailed when they were formed with those which are taking place before our eyes in the world of to-day. A sand-grain

[1] Published by the Geological Survey of India (1925). Scale 1 in. =32 miles.

or a pebble of the rocks is not a mere particle of inanimate matter, but is a *word* or a *phrase* in the history of the earth, and has much to tell of a long chain of natural operations which were concerned in its formation Similarly, a fossil shell is not a mere chance relic of an animal that once lived, but a valuable *document* whose preservation is to be reckoned an important event in the history of the earth. That mollusc to which the shell belonged was the heir to a long line of ancestors and itself was the progenitor of a long line of descendants. Its fossil shell marks a definite stage in the evolution of life on earth that was reached at the time of its existence, which definite period of time it has helped to register. Often it tells much more than this, of the geography and climate of the epoch, of its contemporaries and its rival species. In this way, by a judicious use of the imagination, is the bare skeleton given a form and clothed ; the geological records then cease to be an unintelligent mass of facts, a burden to memory, and become a living story of the various stages of the earth's evolution.

One word more In reading stratigraphical geology the student should remind himself, often and often, and take note of the illustrations of the principles of dynamical and tectonic geology, of which every page of historical geology is full. Many of the facts of dynamical and structural geology find a pertinent illustration by the part they play in the structure or history of a particular country or district. The problems of crust-deformations, of vulcanicity, of the variations, migrations and extinctions of life-forms with the passage of time, and a host of other minor questions that are inscribed in the pages of the rock-register, must be thought over and interpreted with the clue that modern agencies in the earth's dynamics furnish

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TABLE OF THE GEOLOGICAL FORMATIONS OF INDIA.

	Peninsula.	Himalayas	Salt-Range.	Other Areas	Age.
Aryan Group.	Newer alluvium of the deltas; newer raised-beaches; coral banks Cave-deposits of Karnul.	Modern river-deposits Dry deltas, fans, etc	Blown sand, loess; travertine, etc	Newer alluvium— *Khadar* of the Indus and the Ganges	*Recent*
	Older alluvium of the Narbada, Godavari, etc.; *Palaeolithic* gravels; low-level *laterite*; *Porbander* sandstone, raised-beaches; sand dunes; loess; desert sands of Rajputana and Cutch. **Cuddalore sandstone.**	**Ice Age.** Glacial moraines; perched blocks, etc.; *Upper Karewas* of Kashmir; old high-level alluvia of the Sutlej, etc. River-terraces and gravels.	Loess deposits. Travertine masses.	**The Indo-Gangetic Alluvium**— *Bhangar* Loess of Baluchistan.	*Pleistocene.*
	Laterite (high-level) of the Peninsula. Ossiferous conglomerate of Perim island.	**Siwalik System.** *Upper Siwalik.* *Middle Siwalik* *Lower Siwalik* or *Nahan*	**Siwalik System.** *Upper Siwalik* *Middle Siwalik* *Lower Siwalik.*	**Siwalik System.** [Irrawaddy System of Burma *Manchar* System of Sind.]	*Pliocene* *Upper Miocene* *Middle Miocene.*
	Cuddalore Series of the East Coast (part); *Gaj* Series of Cutch, Tertiary of Quilon.	*Upper Murree* Series of Punjab Himalayas; *Kasauli* Series of Simla Himalayas. *Lower Murree*; *Dagshai* series.	—	*Burma.* | *Sind and Baluchistan* **Pegu System.** | **Mekran System.** Intrusive granites, syenites, etc. *Kama* clays and Assam oil-beds. | **Gaj Series of Sind.** *Prome* Series. | *Flysch* of Baluchistan.	*Lower Miocene*
	Nari Series of Cutch; *Dwarka* beds of Kathiawar	*Fatehjang* beds. Intrusive granites, etc., in the core of the Himalayas.	—	*Sitsayan* shales | *Bugti* beds. **Nari Series of Sind.**	*Oligocene.*

TABLE OF THE GEOLOGICAL FORMATIONS OF INDIA—*Continued.*

ARYAN GROUP (*contd.*).

Peninsula.	Himalayas.	Salt-Range.	Other Areas.	Age.
Nummulitics of Surat and Broach, Lower Tertiaries of Cutch; nummulitic limestone of Rajputana. *Laki* Series of Bikaner	*Subathu* and *Chharat* Series of Outer Himalayas; Lower Tertiaries of the Inner Himalayas, Indus Valley and Hundes. Coal-bearing beds of Jammu *Laki* Series of Kohat. Hill Limestone of Hazara and Punjab	**Nummulitic limestone.** *Laki* Series of Eastern Range.	**Kirthar Series** (nummulitic limestone) of Assam, **Sind** and Baluchistan, Upper Eocene of Burma. **Laki Series of Assam, Sind and Baluchistan.** **Ranikot Series of Sind.** **Paunggyi** Conglomerate of Burma.	*Upper Eocene* *Lower Eocene.*
South-East Coast *Ninyur Stage*, *Ariyalur* „, *Trichinopoly* „, *Uttatur* „ — **Cretaceous.** **Deccan Trap.** *Lameta* Series. *Bagh* beds	**Cretaceous of Central Himalayas.** [Plutonic and volcanic igneous rocks] *Flysch* of C. Himalayas. *Chikkim* Series of North Himalayas. *Giumal* sandstone of Spiti and Hazara.	*Cardita beaumonti* beds. Cretaceous of West Salt Range—Chichali.	Intrusive granite, gabbros, and serpentine of Baluchistan and Burma *Cardita beaumonti* beds and *Pab* sandstone of Sind and Baluchistan. Cretaceous of Assam and Burma. *Parh* limestone of Baluchistan.	*Danian.* *Cenomanian.* *Weald.*
Upper Gondwana System. *Umia* Series. *Jabalpur* Series. *Rajmahal* Series. — **Marine Jurassic of Cutch.** *Umia* Series. *Katrol* Series. *Chari* Series *Patcham* Series. **Marine beds in the East Coast Gondwanas**	**Jura of the Himalayas.** *Spiti* shales *Kioto* limestone { *Tagling* stage. *Para* stage (*Megalodon* limestone) } *Tal* Series of Garhwal	Upper and Middle Jurassic of the West Salt-Range—Chichali range.	Massive limestone of Baluchistan (Oolite) Black crinoidal limestone of Baluchistan (Lias) *Namyau* beds of Northern Shan States	*Jurassic.*

Group	Peninsula.	Himalayas.	Salt-Range.	Other Areas	Age
Aryan Group (*contd.*).	**Middle Gondwana System.** *Maleri* Series. *Parsora* stage. *Kamthi* Series. *Panchet* Series.	**Trias of the Himalayas.** Upper Trias. Middle Trias. Lower Trias (*Otoceras* zone)	**Trias of Salt-Range.** — Middle Trias Lower Trias (*Ceratite* beds)	Upper Trias of Baluchistan and *Napeng* beds of Burma. — —	*Triassic*
	Lower Gondwana System. *Damuda* Series. { *Raniganj* Stage *Ironstone* shales stage *Barakar* Stage Productus bed of Umaria. *Talchir* Series. { *Karharbari* Stage. *Talchir* " (Talchir boulder-bed.)	**Permian of the Himalayas.** *Zewan* Series of Kashmir and the *Productus* shales of Spiti and the Central Himalayas. **Gondwanas of N.W. Himalayas** *Gangamopteris* beds of Kashmir.	**Productus limestone.** *Productus* limestone Speckled sandstone. Boulder-bed.	*Plateau* limestone— Upper part, of the Northern Shan States	*Permian* *Permo-Carboniferous.*
Dravidian Group.	.	**Carboniferous of Spiti and Kashmir.** *Panjal* Volcanics. *Po* Series of Spiti and *Fenestella* shales of Kashmir. *Lipak* Series of Spiti. *Syringothyris* limestone of Kashmir		*Plateau* limestone— Middle part, of the Northern Shan States *Fusulina* limestone of Baluchistan. *Plateau* limestone— Lower part, of the Northern Shan States	*Middle and Upper Carboniferous* *Lower Carboniferous.*

TABLE OF THE GEOLOGICAL FORMATIONS OF INDIA—*Continued.*

	Peninsula	Himalayas	Salt-Range	Other Areas	Age
Dravidian Group (*contd.*).		*Muth* Series of Spiti and Kashmir. Devonian limestones of Hazara and Chitral.		**Devonian of Burma.** Crystalline limestones of Padaupkin. *Wetwin* shales	*Devonian*
		Silurian of Spiti and Kashmir. Fossiliferous Silurian beds of Spiti and Kashmir		*Zebingyi* Series. *Namshim* sandstone	*Silurian*
		Ordovician of Spiti and Kashmir. Fossiliferous Ordovician beds in Central Himalayas and in Kashmir		*Nang Kangyi* Series of Northern Shan States.	*Ordovician*
		Cambrian of Spiti and Kashmir. *Haimanta* System of Central Himalayas. Cambrian (?) of Kashmir.	**Cambrian of Salt-Range.** *Magnesian* sandstone *Neobolus* beds Purple sandstone. Red Salt-Marl (?)	*Chang Magyi* Series of Northern Shan States	*Cambrian*

Group	Peninsula	Himalayas	Salt-Range	Other Areas	Age
Purana Group.	**Vindhyan System.** Upper *Bhander* Series *Rewa* Series. *Kaimur* Series. ——— Lower *Karnul* Series *Malani* Series. Intrusive granites of *Jalor* and *Siwana*. **Cuddapah System.** Upper *Nallamalai*, *Kistna*, and *Kaladgi* Series. ——— Lower *Bijawar*, *Cheyair*, and *Gwalior* Series. *Papaghani* Series.	*Attock* Series of Peshawar and Hazara. *Baxa* Series of Eastern Himalayas *Deoban*, *Daling*, *Krol* and *Infra-Krol* Series of Central Himalayas.			*Torridonian* *Algonkian*.
Archaean Group.	**Archaean System.** *Dharwar* System. *Aravalli Series* *Champaner* ,, *Shillong* ,, *Gondite* ,, *Kodurite* ,,	*Vaikrita* Series of Spiti; *Daling* of Eastern Himalayas; *Jaunsar* and lower part of the *Simla System* of Central Himalayas.		Crystalline limestones, etc., of Burma.	*Huronian* (*Archaean*.)
Archaean Group. (Gneisses and Granites.)	*Charnockite* gneisses and granites of South India *Bundelkhand* gneiss— Massive granulated gneiss *Bengal* gneiss and *Schistose* gneisses of the Peninsula.	"Central gneiss" in part		Archaean fundamental gneiss and intrusive granites of Burma, Assam, Baluchistan, etc.	*Lewisian*. (*Archaean*.)

CHAPTER III

THE ARCHAEAN SYSTEM

General.

THE oldest rocks of the earth's crust that have been found at the bottom of the stratified deposits, in all countries of the world, exhibit similar characters regarding their structure as well as their composition. They form the core of all the great mountain-chains of the world and the foundations of all its great ancient plateaus. They are all *azoic*, thoroughly crystalline, extremely contorted and faulted, are largely intruded by plutonic intrusions, and generally have a well-defined foliated structure. These conditions have imparted to the Archaean rocks such an extreme complexity of characters and relations that the system is often known by the names of the "Fundamental Complex," the "Basement Complex," etc. (Fig. 3.)

The way in which the Archaean crystalline rocks have originated is not well understood yet, and various modes of formation have been ascribed to these rocks: (1) Some are believed to represent, in part at least, the first-formed crust of the earth by the consolidation of the gaseous or molten planet. (2) Some are believed to be the earliest sediments formed under conditions in many respects different from those existing at later dates and laid down in the primeval ocean basins and which have undergone an extreme degree of thermal and regional metamorphism (3) Some are thought to be the result of the bodily deformation or metamorphism of large plutonic igneous masses under great earth-movements or stresses. (4) Some are believed to be the result of the consolidation of an original heterogeneous magma erupted successively in the crust (cf. the banded gabbros)

Distribution.

The crystalline and gneissic rocks of the Archaean system

form an enormous extent of the surface of India. By far the largest part of the Peninsula, the Central and Southern, is occupied by this ancient crystalline complex. To the north-east they occupy wide areas in Orissa, Central Provinces and Chota Nagpur. Towards the north the same rocks are

(about 1/15 natural size)

FIG. 3 —Diagram showing contortion in the Archaean gneiss of Bangalore.

exposed in an extensive outcrop covering the whole of Bundelkhand; while to the north-west they are found in a number of isolated outcrops, extending from north of Baroda to a long distance in the Aravallis and Rajputana.

In the extra-Peninsula, gneisses and crystalline rocks are again exposed along the whole length of the Himalayas, building all their highest ranges and forming the very backbone of the mountain-system. This *Crystalline axis* runs as a broad

central zone from the Karakoram and the Kashmir ranges to the eastern extremity in Burma. The eastern part of the Himalayas, from Nepal eastwards, has not been explored, with the exception of Sikkim, but it is certain that the crystalline zone is quite continuous It is a matter of great uncertainty, however, what part of the great gneissic complex of the Himalayas represents the Archaean system, because much of it is now ascertained to be highly metamorphosed granites or other intrusives of late Mesozoic or even Tertiary ages. The Himalayan gneiss has been designated as the "Central" or "Fundamental" gneiss.

A fairly broad crystalline zone, similar to the gneisses of the Peninsula, runs along Burma from north to south, constituting the Martaban system of the southern or Tenasserim division, and the Mogok gneiss of North Burma

Petrology of the Archaean system.

Over all these areas of many hundred thousand square miles, the most common Archaean rock is *gneiss*—a rock which in mineral composition may vary from granite to gabbro, but which possesses a constant, more or less foliated or banded structure, designated as *gneissic*. This characteristic banded or streaky character may be either due to an alternation of bands or layers of the different constituent minerals of the rock, or to the association of layers of rocks of varying mineral composition. At many places the gneiss appears to be a mere intrusive granite, exhibiting clearly intrusive relations to its neighbours. The gneiss, again, frequently shows great lack of uniformity either of composition or of structure, and varies from place to place At times it is very finely foliated, with folia of exceeding thinness alternating with one another; at other times there is hardly any foliation or schistosity at all, the rock looking perfectly granitoid in appearance. The texture also varies between wide limits, from a coarse holocrystalline rock, with individual phenocrysts as large as one or two inches, to almost a felsite with a texture so fine that the rock appears quite homogeneous to the eye.

The constituent minerals of the commoner types of the Archaean gneiss are: orthoclase, oligoclase or microcline, quartz muscovite, biotite, and hornblende with a variable amount of accessory minerals and some secondary or alteration

products, like chlorite, tourmaline, epidote and kaolin Orthoclase is the most abundant constituent, and gives the characteristic pink or white colour to the rock. Plagioclase is subordinate in amount; quartz also is present in variable quantities: hornblende and biotite are the most usual ferro-magnesian constituents, and give rise to the hornblende and biotite-gneisses, which are the most prevalent rocks of the Central ranges over wide tracts of the Himalayas. Tourmaline is an essential constituent of some gneisses of the Himalayas. Chlorite occurs as a secondary product, replacing either hornblende or biotite. Less frequent minerals, and occurring either in the main mass or in the pegmatite veins that cross them, are apatite, epidote, garnets, scapolite, wollastonite, beryl, tourmaline, tremolite, actinolite, jadeite, corundum, sillimanite together with spinels, ilmenite, rutile, zircon, graphite, iron ore, etc. Besides the composition of the gneiss being very variable over wide areas, almost all gradations are to be seen, from thoroughly acid to intermediate and basic composition (granite-gneiss, syenite-gneiss, diorite-gneiss, gabbro-gneiss)

By the disappearance of the felspars the gneisses pass into schists, which are the next abundant components of the Archaean system of India. The schists are for the most part thoroughly crystalline, mica-, hornblende-, talc-, chlorite-, epidote-, sillimanite- and graphite-schists. Mica-schists are the most common, and are often garnetiferous. Less common rocks of the Archaean of India, and occurring separately or as interbedded lenses or bands in the main complex, are granulites, crystalline limestones (marbles), dolomites, graphite, iron-ores, and some other mineral masses. The gneisses and schists are further traversed by an extensive system of basic trap-dykes of dioritic or doleritic composition.

But the Archaean group of India, as of the other countries of the world, is far more complex in its constitution than is expressed by the above few simple statements. In it, though several concrete petrological elements have been recognised, yet their relations are so very intimate that separation of these is very difficult or impossible. Among these gneisses and schists those which, by reason of their chemical and

mineralogical composition, are believed to be the highly deformed and metamorphosed equivalents of plutonic igneous masses, are known as orthogneisses or orthoschists, while others that suggest the characters of highly altered sediments deposited in the ancient seas are known as para-gneisses or para-schists ; a third kind again is also distinguished, which, according to some authors, may be the original first-formed crust of the earth. It thus appears that the Indian Archaean representatives do not belong to any one petrological system, but are a "complex" of several factors · (1) an ancient fundamental basement complex into which, (2) a series of plutonic rocks are intruded, like the Charnockites and some varieties of Bundelkhand gneisses, while there is (3) a factor representing highly metamorphosed schistose sediments, the para-gneisses and schists, which probably are mainly of Dharwar age, and are generally younger than the (1) gneisses.

Petrological types.

Associated with the Archaean gneisses and schists there are some interesting petrological types discovered during the progress of the Indian Geological Survey, which the student should know. Some of these are described below :

Granite.	Of North Arcot.
Augite-granite. Augite-syenite (Laurvikite).	Of Salem.
Nepheline-syenite. Elaeolite-syenites and their pegmatites.	Of Coimbatore, Vizagapatam, Kishengarh (Rajputana) and Junagadh (Kathiawar). These are a group of intermediate plutonic rocks foliated among the gneisses. Among their normal essential minerals are *calcite* and *graphite* in a quite fresh state. The type elaeolite-syenite of Kishengarh contains large crystals of beautiful blue *sodalite* with *scapolite*, *sphene*, garnet, etc., as accessories.
Elaeolite-syenite. Augite-syenite. Corundum-syenite.	Of the Coimbatore district, constitute the so-called *Sivamalai* series of Holland. These are genetically related rocks, all derived from a common highly aluminous magma.
1. Charnockite. 2. Augite-norite. 3. Norite. 4. Hyperite. 5. Olivine-norite. 6. Pyroxenite.	Of Madras and Bengal are acid intermediate, basic and ultra-basic members respectively of a highly differentiated series of holocrystalline, granitoid, hypersthene-bearing rocks of the Peninsula distinguished by Holland and named by him Charnockite

7. Anorthosite. 8. Granulite. 9. Garnetiferous-leptynite. 10. Pyroxene-diorite. 11. Scapolite-diorite.	series from Charnock, the founder of Calcutta. (See Charnockite series below.)
Khondalite (Quartz + sillimanite + garnet + graphite).	Named after the Khonds of Orissa, occurs in Orissa, Central Provinces, etc ; are light-coloured richly garnetiferous gneisses and schists characterised by the abundance of the mineral sillimanite and the presence of graphite. They are regarded as para-gneisses and schists.[1]
1. Gondite (Quartz + manganese-garnet + rhodonite). 2. Rhodonite rock.	Named from the Gonds of the Central Provinces by Dr. L. Fermor. These are a series of meta-morphosed rocks belonging to the Archaean and Dharwar systems and largely composed of quartz, spessartite, rhodonite and other manganese-silicates. These rocks are sup-posed to be the product of the dynamic metamorphism of manganiferous clays and sands deposited during Dharwar times. On the chemical alteration of the manganese-silicates so produced, these rocks have yielded the abundant manganese-ores of the Dharwar system.
Kodurite (Orthoclase + manganese-garnet + apatite).	From Kodur in Vizagapatam district. These are a group of plutonic rocks, associated with the Khondalite series and possibly of hybrid origin. The normal type, or *Kodu-rite* proper has the composition noted above, and is a basic plutonic rock classified with Shonkinites, but there are acid as well as ultra-basic varieties of the series like the *spandite-rock*, *manganese-pyroxenite*, con-taining manganese-garnet, -amphibole, -pyroxene, -sphene, etc, at one end, and quartz-orthoclase rock and quartz-kodurite at the other. These rocks also have yielded manganese-ores of economic value by chemi-cal alteration.
Calc-gneiss, calciphyres and crystalline limestones.	The first two of these are highly calcareous rocks which are found associated with the Archaean rocks of the Central Provinces and some other localities in India. They are a series of granulite-like rocks with an un-usually high preponderance of lime-silicates, diopside, hornblende, labradorite, epidote, garnet, sphene, and similar alumino-calcareous silicates. From such a composition, they are believed to be para-gneisses, *i.e.* formed by

[1] *Mem. G.S.I.* vol. xxxiii. pt. 3, 1902.

the metamorphism of a pre-existing calcareous and argillaceous series of sediments

The oxidation by meteoric agencies of these series has given rise to the crystalline limestones, the third class of rocks mentioned in the heading. These are very intimately associated with the two former rocks in the Central Provinces and in Burma The abundant lime and magnesian silicates of these gneisses have been altered by percolating waters, carrying dissolved CO_2, into calcite and magnesite. Besides the crystalline limes and dolomites of the Central Provinces, the famous ruby-limestone associated with the Mogok gneiss of Burma is another example. The origin of these limestones was a puzzle because they could not be explained on the supposition of their being of either sedimentary, organic or chemical deposition.[1]

Quartz-haematite schist. Quartz-magnetite schist. — Composed of quartz and haematite or quartz and magnetite. These are of very common prevalence in many parts of South India, especially among the Dharwar schists. The iron-ore and quartz are generally in very intimate association arranged in thin layers or folia.

Classification.

The gneissic Archaean rocks of India are classified into the following more or less well-defined groups, though they do not represent any definite succession in time:

1. *Bengal gneiss*—Highly foliated, heterogeneous, schistose gneisses and schists, of Bengal, Behar, Orissa, Carnatic and large tracts of the Peninsula.
2. *Bundelkhand gneiss*.—Massive, granitoid gneisses of Bundelkhand and some parts of the Peninsula. This gneiss is regarded as intrusive into the former.
3. *Charnockite series—Nilgiri gneiss*—Massive, eruptive, dark-coloured hypersthene-granitoid gneisses of South India.

(1) BENGAL GNEISS is very finely foliated, of heterogeneous composition, the different schistose planes being characterised by material of different composition. This gneiss is closely associated with schists of various composition. The gneiss is often dioritic, owing to the larger proportion of the plagioclase

[1] Fermor, *Rec.* vol. xxxiii pt. 3, 1906.

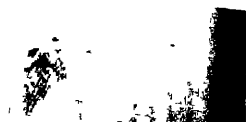
present Numerous intercalated beds of limestones, dolomites, hornblende-rock, epidote-rock, corundum-rock, etc., occur among the gneiss. There is an abundance of accessory minerals, contained both in the rock itself and in the accessory beds associated with it, such as magnetite, ilmenite, schorl, garnet, calcite, lepidote, beryl, apatite, epidote, corundum, micas, etc In all the above characters the rocks commonly designated Bengal gneiss differ strikingly from those commonly named Bundelkhand gneiss, in which there are no accessory constituents, and but few associated schists.

The weathering of some part of the gneiss of North Bengal is very peculiar ; it gives rise to semi-circular, dome-like hills, or ellipsoidal masses, by the exfoliating of the rock in regularly circular scales From this peculiarity the gneiss has received the name of *Dome gneiss.*

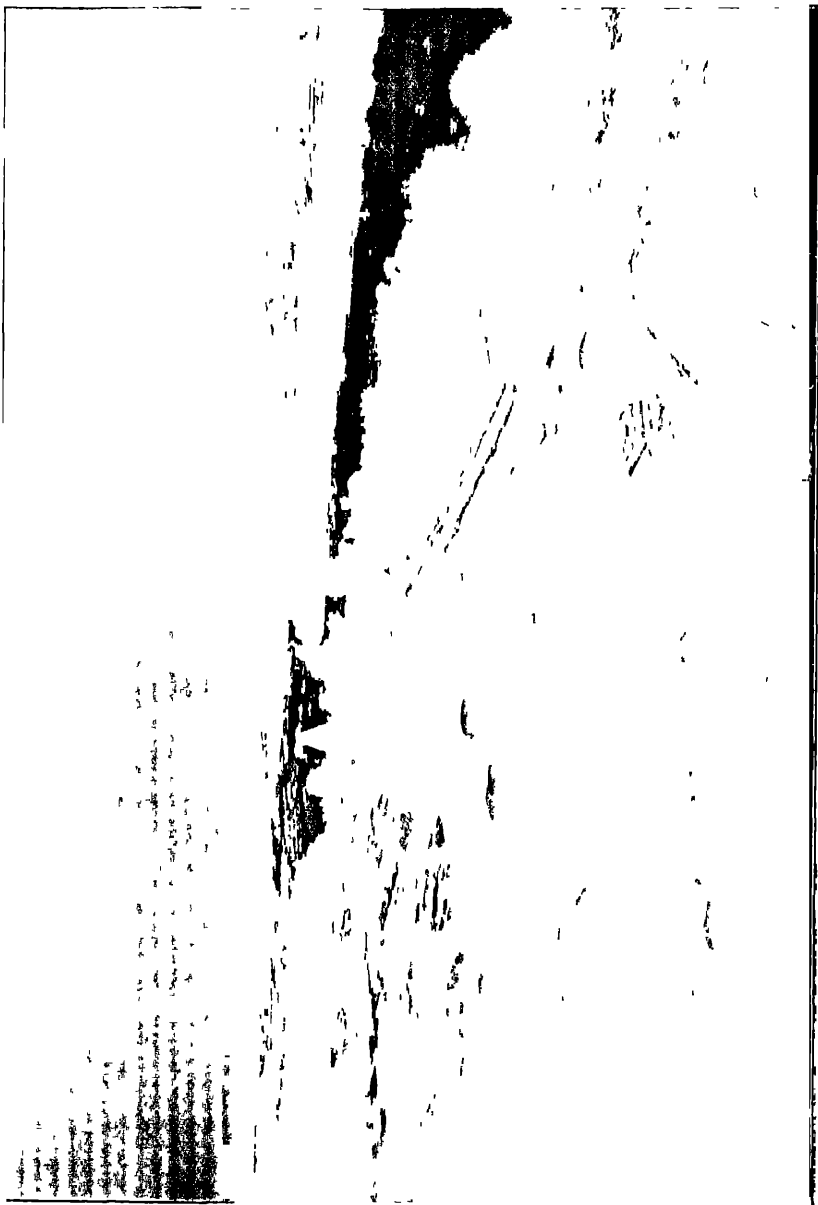
The gneiss in some places of Bengal closely resembles an intrusive granite with well-marked zone of contact-metamorphism in the surrounding gneisses and schists in which it appears to have intruded. Its plutonic nature is further shown in its containing local segregations (autoliths) and inclusions of foreign rock-fragments (xenoliths)

Types of Bengal gneiss.

Besides the foregoing varieties some other petrological types are distinguished in the Bengal gneiss, the most noted being the *Sillimanite-gneiss* and *Sillimanite schist* of Orissa, known as Khondalites (from the Khond inhabitants of Orissa). These give clear evidences of being metamorphosed sediments (para-schists). A large part of the schistose and garnetiferous gneiss of South India, commonly designated " Fundamental gneiss " or " Peninsular gneiss," belongs appropriately to this division. The Bengal gneiss *facies* is revealed in the gneisses of Behar, Manbhum and Rewah, and some other parts of the Peninsula also. The *Carnatic* and *Salem* gneisses are examples. Carnatic gneiss is schistose, including micaceous, talcose, and hornblendic schists. The well-known mica-bearing schists of Nellore, which support the mica mines of the district, belong to the facies of the Bengal gneisses. The schistose type of Bengal gneiss is regarded as probably the oldest member of the Archaean Complex.

(2) BUNDELKHAND GNEISS. Bundelkhand gneiss occurs in the type area of Bundelkhand. It looks a typical pink granite in hand specimens, the foliation being very rude, if at all

developed. In its field relations, the Bundelkhand gneiss differs from ordinary intrusive granite only in the enormous area which it occupies. Indeed, it may be regarded as an intrusive granite, like the Charnockites to be described below, into older gneisses, large patches of which it has remelted. Schists are associated with the gneisses very sparingly, *e.g* hornblende-, talc- and chlorite-schists. No interbedded marbles or dolomites or quartzites occur in the Bundelkhand gneiss, nor is there any development of accessory minerals in the mass of the rock or in the pegmatite-veins Bundelkhand gneiss is traversed by extensive dykes and sills of a coarse-grained diorite, which persist for long distances. It is also traversed by a large number of coarse pegmatite-veins as in a boss of granite. Quartz-veins or reefs (the ultra-acid modification of the pegmatite-veins), of great length, run as long, narrow serrated walls, intersecting each other in all directions, giving to the landscapes of the country a peculiar feature. They intersect the drainage-courses of the district and are the cause of the numerous lakes of Bundelkhand, whose formation can be easily understood and requires no explanation.

This type of gneiss is also met with in the Peninsula at several localities, and is recognised there under various names—*Balaghat gneiss* (also named *Bellary gneiss*), *Hosur gneiss*, *Arcot gneiss*, *Cuddapah gneiss*, etc. The rock is quarried extensively for use as a building-stone, and has in the past contributed material of excellent quality for the building of numerous temples and other edifices of South India

(3) Charnockite series This is the name given to a series of plutonic granitoid rocks of South India, occurring as intrusions into the older Archaean gneisses and schists of the Peninsula These rocks are of wide prevalence in the Madras Presidency, and constitute its chief hill-masses—the Nilgiris, Palnis, Shevaroys, etc. They are medium to coarse-grained, dark-coloured, basic holocrystalline granitoid gneisses, possessing such a distinctive assemblage of petrological characters and mineral composition that they are easily distinguished from the other Archaean rocks of the Peninsula. This group includes many varieties and forms which are modifications of a central type (the Charnockite proper), but these different varieties exhibit a distinct "consanguinity" or family relationship to each other. From this

BELLARY GRANITE, GNEISS COUNTRY, HAMPI

circumstance the Charnockite gneisses of South India afford a very good instance of a *Petrographical province* within the Indian region. The name Charnockite which was originally given by the discoverer of these rocks, Sir T. H Holland, to the type-rock from near Madras, is now, therefore, extended by him (Charnockite series) to include all the more or less closely related varieties occurring in various parts of the Madras Presidency and other parts of the Peninsula

Petrological characters.

The mineralogical characters which give to these rocks their distinctive characters are . The almost constant presence of the rhombic pyroxene, hypersthene or enstatite, and a high proportion of the dark ferromagnesian compounds which impart to the rock its usual dark colours The ordinary constituents of the rock include blue-coloured quartz, plagioclases, augite, hornblende and biotite with zircon, iron-ores and graphite as accessories. Garnets are of very common occurrence The presence, in different proportions, of the above constituents imparts to the different varieties a composition varying from an acid or intermediate hypersthene-granite (Charnockite proper) through all gradations of increasing basicity, to that of the ultra-basic felsparless rocks, pyroxenites. The specific gravity and silica per cent range from 2 67 and 75 per cent. respectively, in the normal hypersthene-granite, to 3·03 and 52 per cent. in the norites and hyperites In the pyroxenites the specific gravity rises to 3·37, corresponding to a fall of silica per cent to 48 per cent. These ultra-basic types occur only locally as small lenses or bands in the more acid and commoner types.

That the Charnockites are of the nature of igneous plutonic rocks, intruded into the other Archaean rock-masses, is considered to be established from a number of facts observed relating to their field-characters :

(1) Their usual occurrence in irregular or lenticular sills forming hill-masses, and possessing a general uniformity of composition and mineralogical characters characteristic of plutonic intrusions.

(2) They present evidences of the processes of magmatic differentiation and segregation, and show fine-grained basic secretions and acid excretions (contemporaneous veins, etc).

(3) They show apophyses and dykes protruding into the surrounding older gneisses and schists.

(4) At some places well-defined contact-phenomena are exhibited at their junction with the rocks they have invaded. Such rocks as quartzites and limestone show this in a pronounced manner, e g. the production of such minerals as sillimanite and corundum in the former, and scapolite, sphene and lime-garnets in the latter

The Charnockite series is mainly confined to the Madras Presidency and South India; a few of its types, viz. *anorthosites*, a rock principally composed of anorthite felspar, and *olivine-norites*, are found in Bengal near Raniganj

Microscopic characters.

[A thin section of Charnockite of average composition under the microscope shows an hypidiomorphic aggregate of large plates of microcline or any other plagioclase and quartz, with allotriomorphic plates of hypersthene, and a few grains of pink garnet with irregular outlines. The accessories are crystals of magnetite, or ilmenite, and sometimes very small grains of zircon. The quartz is often crowded with acicular inclusions, which are disposed parallel to its crystallographic axes. The microcline occurs in large clear prisms and plates, with its characteristic twin-striations; it is often *perthitic*, by intergrowth with another plagioclase The quartz at times shows graphic relations to the felspar. The felspars vary from oligoclase to labradorite Garnet is commonly seen in irregular crystals, with numerous anisotropic inclusions. The garnets are believed to have orignated by the interaction between hypersthene and felspar, and they are usually found in the zone of reaction between the two. Free silica is eliminated during the process, and is distributed as pegmatitic intergrowth with the garnets Hypersthene is invariably present as a primary constituent, but in variable quantity according to the basicity of the rock; it is distinctly pleochroic, shows schiller inclusions, straight extinction, and its characteristic interference colours. It is generally accompanied by hornblende and augite in the less basic varieties. Among the accessories are black opaque crystalline aggregates of magnetite and ilmenite with apatite and zircon, the latter is found in very minute grains. The minerals of Charnockite are usually all fresh, there being very little evidence of decomposition.]

Archaean of the Himalayas

As already said, the bulk of the high ranges of the Himalayas forming the central or Himalayan zone proper is formed of crystalline or metamorphic rocks, like granites, gneisses, and schists. In this complex, known formerly as the Central

PLATE V

BANDED PORPHYRITIC GNEISS (YOUNGER ARCHAEAN), NAKTA NALA, CHHINDWARA DISTRICT,

Geol. Survey of India, Records, xliii pl. 1

gneiss, from its occupying the central axis of the mountain chain from one extremity to the other, the representatives of the Archaean gneisses of the Peninsula are to be found. It is, however, difficult to know how many of these are of Archaean age, for it is now known for certain, by the researches of General MacMahon and later investigators, that much of it is of intrusive origin, and, therefore, of very much younger age. In fact, over large tracts they have been proved to be of Cretaceous and Miocene ages. These granites have passed into gneisses by assuming a foliated structure, while the Archaean gneiss proper has assumed the aspect of granites, owing to the high degree of dynamic metamorphism. It is again quite probable that a certain proportion of the central gneiss is to be attributed to highly metamorphosed ancient (Purana) sediments. It is therefore difficult to separate from this complex the constituent elements of the Archaean gneiss from gneissose granite or from the metamorphosed sediments of later age.

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CHAPTER IV

ARCHAEAN SYSTEM (*contd.*)

THE DHARWAR SYSTEM

General. ACCORDING to the commonly received interpretation, during the later stages of the Archaean era the meteoric conditions of the earth appear to have been changing gradually. We may suppose that the decreasing temperature, due to continual radiation, condensed most of the vapours that were held in the thick primitive atmosphere and precipitated them on the earth's surface. The condensed vapours collected into the hollows and corrugations of the lithosphere, and thus gave rise to the first-formed ocean. Further loss of heat produced condensation in the original bulk of the planet, and as the outer crust had to accommodate itself to the steady diminution of the interior, the first-formed wrinkles and inequalities became more and more accentuated The oceans became deeper, and the land-masses, the skeletons of the first continents, rose more and more above the general surface. The outlines of the seas and continents being thus established, the geological agents of denudation entered upon their work. The weathering of the older Archaean gneisses and schists yielded the earliest sediments which were deposited on the bed of the sea, and formed the oldest sedimentary strata, known in the geology of India as the Dharwar System.

These sedimentary strata appear to rest over the gneisses at some places with a great unconformity, while at others they are largely interbedded with them, and in some cases are of undoubtedly older age than some of the gneisses. Although, for the greater part at least, of undoubted

sedimentary origin, the Dharwar strata are altogether unfossiliferous, a circumstance to be explained as much by their extremely early age, when no organic beings peopled the earth, as by the great degree of metamorphism they have undergone The complex foldings of the crust in which these rocks have been involved have obliterated nearly all traces of their sedimentary nature, and have given to them a thoroughly crystalline and schistose structure, hardly to be distinguished from the underlying gneisses and schists. They are besides extensively intruded by granitic bosses and veins and sheets, and by an extensive system of dolerite dykes, thus rendering these rock-masses still more difficult of identification

Outcrops of the Dharwar rocks

One important peculiarity regarding the mode of occurrence of the Dharwar rocks—as of generally all other occurrences of the oldest sediments that have survived up to the present—is that they occur in narrow elongated synclinal outcrops among the gneissic Archaeans—as outliers in them. This tectonic peculiarity is due to the fact that only those portions of the Dharwar beds that were involved in the troughs of synclinal folds and have, consequently, received a great deal of compression, are preserved, the limbs of the synclines, together with their connecting anticlinal tops, having been planed down by the weathering of ages.

The lithology of the Dharwars

The rocks of this system possess the most diverse lithological characters, being a complex of all kinds of rocks—clastic sediments, chemically precipitated rocks, volcanic and plutonic rocks—all of which show an intense degree of metamorphism No other system furnishes such excellent material for the study of the various aspects of rock-metamorphism. The rocks are often highly metalliferous, containing ores of iron and manganese, occasionally also of copper, lead, and gold. The bulk of the rocks of the system is formed of phyllites, schists, and slates. These are hornblende-, chlorite-, haematite- and magnetite-schists, felspathic schists ; quartzites and highly altered volcanic rocks, *e g.* rhyolites and andesites turned into hornblende-schists ; abundant and widespread granitic intrusions ; crystalline limestones and

marbles; serpentinous marbles; steatite masses; beds of brilliantly coloured and ribboned jaspers; roofing slates; and massive beds of iron and manganese oxides

Plutonic intrusions of Dharwar.

The plutonic intrusions assumed to be of Dharwar age have given rise to some interesting rock-types, some of which have already been described in the last chapter, viz nepheline-syenites of Rajputana, differentiated into the elaeolite-syenite and sodalite-syenite of Kishengarh, which carry the beautiful mineral sodalite. Many of the granites of the Dharwar system are tourmaline-granites; among other intrusives are the quartz-porphyry of Rajputana, and the dunites of Salem The pegmatite-veins intersecting some of the plutonics are often very coarse, and, especially when they cut through mica-schists, bear extremely large crystals of muscovite, the cleavage sheets of which are of great commercial value. Such is particularly the case with the mica-schists of Hazaribagh, Nellore, and parts of Rajputana, where a large quantity of mica is quarried Besides muscovite, the pegmatites carry several other beautifully crystallised rare minerals, *e.g.* molybdenite, columbite, pitch-blende, gadolinite, torbernite, etc.

Crystalline limestones originating by metasomatism of gneisses

Here must also be considered the curious group of manganiferous crystalline limestones of Nagpur and Chhindwara districts of the Central Provinces, containing such minerals as piedmontite (Mn-epidote), spessartite (Mn-garnet), with Mn-pyroxene, -amphibole, -sphene, etc, which have given rise, on subsequent alteration, to some quantity of manganese ores As mentioned on p. 53, these crystalline limestones are attributed a curious mode of origin. Dr. Fermor has shown them to be due to the metasomatic replacement of Archaean calc-gneisses and calciphyres, which in turn were themselves the product of the regional metamorphism of highly calcareous and manganiferous sediments [1]

Another peculiar rock is the *flexible sandstone* of Jind (Kaliana). The rock was originally formed from the decomposition of the gneisses, and had a certain proportion of felspar grains in it. On the subsequent decomposition of the felspar grains the rock became a mass of loosely interlocking grains of quartz, with

[1] *Rec G S I* vol. xxxiii pt. 3, 1906.

wide interspaces around them, which allow a certain amount of flexibility in the stone.

Distribution of the Dharwars.

The Dharwar rocks are very closely associated with the Archaean gneisses and schists in many parts of the Peninsula. The principal exposures in the Peninsula are three: (1) Southern Deccan, including the type-area of Dharwar and Bellary and the greater part of the Mysore State; (2) the Dharwar areas of Carnatic, Chota Nagpur, Jabalpur, Nagpur, etc.; with those of Behar, Rewah and Hazaribagh; (3) the Aravalli region, extending as far northwards as Delhi, and in its southern extremity including north Gujarat In the extra-Peninsula the Dharwar system is probably well represented in the Himalayas, both in the central and northern zones, as well as in the Shillong plateau of the Assam ranges

1. DHARWAR (*the Type-area*). The rocks occur in a number of narrow elongated bands, the bottoms of old synclines, extending from the southern margin of the Deccan traps to the Cauvery. The general dip of the strata is towards the middle of the bands. The constituent rocks are hornblende-, chlorite-, talc-schists, together with slates, quartzite, and conglomerates and very characteristic brilliantly-banded cherts; these rocks are associated with various types of ortho-gneisses and schists and lavas of dioritic composition. The Dharwar slates exhibit all the intermediate stages of metamorphism (anamorphism) into schists, viz. unaltered slates, chiastolite-slates, phyllites and mica-schists Numerous quartz-veins or reefs traverse the Dharwar rocks of these areas. Some of those are auriferous and contain enough of disseminated gold to support some goldfields. The principal gold-mining centre in India, the Kolar fields in the Mysore State, is situated on the outcrops of some of these quartz-veins or reefs. For a fuller account the student is referred to the publications of the Mysore State Geological Department.[1]

Aravalli mountains

2. RAJPUTANA (*the Aravalli series*) Dharwar rocks are exposed in a very large outcrop in the Aravalli range of Rajputana. This, the most ancient mountain-chain of India, came into existence at the close of the Dharwar era, when the

[1] Sampat Iyengar: "Acid Rocks of Mysore," *Seventh Indian Science Congress Proceedings*, Calcutta, 1921.

sediments that were deposited in the seas of that age were ridged up by an upheaval of orogenic nature Since then the Aravalli mountains remained the principal feature in the geography of India for many ages, performing all the functions of a great mountain-chain and contributing their sediments to many deposits of later ages. Evidence exists that this mountain-chain was of far greater proportions in past times, and that it stretched from the Deccan to perhaps beyond the limits of the Himalayas.

Aravalli series.

The Dharwarian rocks of the Aravalli region, known under the name of the Aravalli series, resemble in their lithological composition the rocks just described in the type-area, but are distinguished from them by a great development of crystalline limestones and quartzites in some localities The famous Mekrana and Jodhpur marbles, the source of the material for the celebrated Mogul buildings of Delhi and Agra, are derived from these rocks Among the common rocks of the Aravalli series are quartzites, mica-schists, hornblende-schists, calciphyres, with schistose conglomerates The schists include numerous secondary aluminous and calcareous silicates like andalusite, sillimanite, staurolite, and a large number of garnets. At some places the Aravalli series includes lodes of copper, with traces of nickel and cobalt, which were largely worked by the ancients. Granite and amphibolite have intruded at many places in the slates and phyllites in the form of veins, attended with off-shoots of quartz-veins and pegmatites A northern outlier of the Aravalli series, composed principally of quartzites, with a lower stage composed of slates and limestones, forms the famous Ridge of the city of Delhi and some isolated outcrops in the neighbourhood. These constitute the *Delhi series*

Delhi series.

The Delhi series is now generally regarded as being much newer and belonging to the Cuddapah group, being separated from the lower division by an unconformity [1] The upper part of the series, largely made up of quartzites, together with arkose, slates and conglomerates, is also known under the name of the *Alwar quartzite* The Alwar quartzite is a thin-bedded quartzose flagstone, which is in great demand

[1] A M. Heron, *Mem. G.S I* vol. xlv. pt. 1 (1917)

s a building stone. On a still further prolongation of the ıravallı strike to the interior of the plains of the Punjab, few small straggling outliers of the same rock-series are iscovered, composed of ferruginous quartzite and slate, ogether with a great development of rhyolitic lavas 'hese outliers constitute the low, deeply weathered hills nown as Kirana and Sangla, lying between the Jhelum nd the Chenab.[1]

Champaner series

One further outlier of the Aravalli series, but this time to he south-west extremity of its strike, is found in the vicinity f Baroda on the site of the ancient city of Champaner. t overspreads a large area of northern Gujarat and is nown as the *Champaner series* The component rocks are uartzites, conglomerates, slates and limestones, all highly netamorphosed A green and mottled marble of exquisite eauty is quarried from these rocks near Motipura.

Shillong series

The *Shillong series* of the Assam hills is a widely developed group of parallel deposits consisting of a thick series of uartzites, slates and schists, with masses of granitic intrusions nd basic interbedded traps. The Shillong series is for the greater part of its extent overlain by horizontally bedded retaceous sandstones.

Dharwar system of the Central Provinces.

3. THE NORTH-EAST AREA The Dharwar system covers arge connected areas in the Central Provinces and Western Bengal, spreading over Balaghat, Nagpur and Jabalpur listricts, and over Behar, Hazaribagh and Rewah. In these ıreas it possesses a highly characteristic metalliferous facies of leposits which has attracted a great deal of attention lately on ıccount of the ores of manganese and iron associated with it. The lithology of the Dharwars in these exposures is very varying, out each outcrop possesses a sufficient variety of its peculiar 'ock-types to reveal the identity of the system. In the Balaghat district, and probably some other parts of the Central Provinces, the local representatives of the Dharwar are distinguished as the *Chilpi series*, from the Chilpi Ghat, which comprise a great thickness of highly disturbed slates and phyllites, with quartzite and basic trappean intrusions. In Jabalpur the outcrop is distinguished by the occurrences

[1] *Rec G S.I.* vol xliii. pt. 3, 1913.

of perfectly crystalline dolomitic limestones The famous "marble-rocks"[1] of Jabalpur in the Narbada gorge belong to this system In other parts of the Central Provinces and in Rewah, some places in the Bombay Presidency (Panch Mahals), etc, the exposures are distinguished by a richly manganiferous facies, containing large deposits of workable manganese-ores Dr L Fermor has given the name *Gondite series* to these rocks, because of their containing, as their characteristic member, a spessartite-quartz-rock, to which he has given the name of *Gondite* (p. 53). Besides spessartite, the rock contains many other manganese-silicates; it is the decomposition of these manganese-silicates that has given rise to the enormous deposits of manganese-ores contained in these occurrences of the Dharwar system.

Manganiferous deposits of Dharwar system: Kodurite and Gondite series

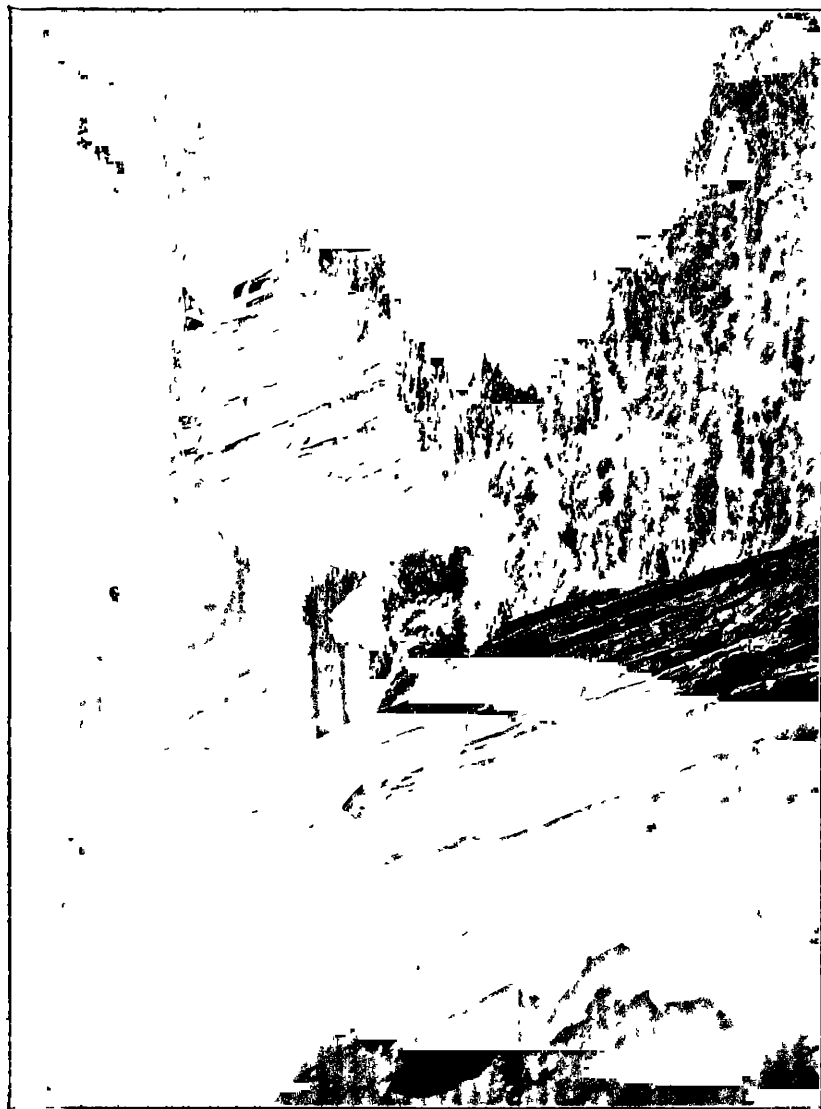
Gondite series

The origin of the Gondite series is interesting According to Dr. Fermor these manganiferous rocks of the Gondite series have resulted from the metamorphism of sediments deposited during Dharwar times which were originally partly mechanical clays and sands, and partly chemical precipitates—chiefly of manganese-oxides. The same metamorphic agencies that have converted the former into slates, phyllites and quartzites, have altered the latter into crystalline manganese-oxides, when pure, and into a number of manganese-silicates where the original precipitates were mixed with clayey or sandy impurities.

Outcrops of the Gondite series are typically developed in the Balaghat, Chhindwara, and Nagpur districts of the Central Provinces and a few localities in Bombay, Central India, and in Banswara in Rajputana.

Kodurite series

The same authority regards the manganese-deposits of the Madras Presidency as due to the alteration of a series of plutonic intrusions (belonging to the *Kodurite series*) which may be of hybrid origin and due to the incorporation in acid intrusives of manganese ore-bodies of the Gondite type. The Kodurite series is typically developed in the Vizianagram State of the Vizagapatam district of Madras.

[1] A series of Dharwar marbles and Cretaceous traps dissected into a number of magnificent dazzling white steeps, through which the Narbada, after its fall (*Dhurandhar*), runs for about two miles in a defile that is barely twenty yards in width.

"MARBLE ROCKS" (DOLOMITE MARBLE), JABALPUR.

Manganese-ores of Dharwar system.

[Almost the whole of the 800,000 tons of *Manganese-ores* annually produced in India is derived directly or indirectly from the Dharwar rocks With regard to their geological relations Dr Fermor has divided the ore bodies into three classes

(1) *Deposits connected with the intrusive rock, Kodurite,* a basic plutonic rock, possessing an exceptional mineralogical composition, in being unusually rich in manganese silicates like manganese-garnets, rhodonite, and manganese-pyroxenes and -amphiboles The ores of the Vizagapatam district have resulted from the meteoric alteration of these manganese-silicates, while the felspar has altered into masses of lithomarge and chert, the other products being wad, ochres, etc The ore-bodies resulting in this manner are of course of extremely irregular form and dimensions and the grade of the ore is low

(2) *Deposits contained in the Gondite series* are developed in the Central Provinces, Central India, Panch Mahals, etc As above described, the Gondite rocks were originally clastic sediments, including precipitates of manganese-oxides like those of iron oxides enclosed in the sedimentary rocks of various ages. Their dynamic or regional metamorphism has given rise to crystallised ores of manganese, like braunite, hausmanite, hollandite, etc. The resulting ore-bodies are large and well-bedded, following the strike of the enclosing rocks, indicating that they have had the same origin as the latter Sometimes, as in Chhindwara and Nagpur, the manganese-ores are found in the crystalline limestone and calc-gneisses associated with the other Dharwar rocks In addition to the ores psilomelane, braunite, hollandite, the crystalline limestone contains usually piedmontite (the manganese-epidote). The Gondite deposits yield by far the largest part of the economically important manganese-ores.

(3) *Lateritic deposits* are due to metasomatic surface replacement of Dharwar slates and schists by manganese-bearing solutions. These ores occur in Singhbhum, Jabalpur, Bellary, etc They are irregular in distribution, occurring as a cap on the outcrops of the Dharwar rocks, as is evident from their peculiar nature of origin

These ore-deposits have brought to light some new mineral species and beautiful crystallised varieties of already recognised manganese minerals. They are *Vredenburgite, Sitaparite*—manganese and iron oxides; *Hollandite* and *Beldongrite* are manganates; *Winchite* is a blue manganese-amphibole, and *Blanfordite* a pleochroic manganese-pyroxene; *Spandite* is a manganese-garnet, intermediate in composition between spessartite and andradite; *Grandite* is similarly a 'hybrid' of grossularite and andradite; *Alurgite* is a pink-coloured manganese-mica.[1]]

4 THE HIMALAYAS. Rocks belonging to this, the oldest sedimentary system, probably occur in a more or less

[1] Fermor, *Mem. S.G I.* vol xxxvii. 1909.

continuous band between the central crystalline axis of the higher Himalayas and the outer ranges Different exposures of these have received different names, according to the localities of their distribution On the north of the crystalline axis, in the district of Spiti, the equivalents of the Dharwars are known as the *Vaikrita series*. On the south of that axis there occur more extensive exposures of metamorphosed highly folded and unfossiliferous sedimentary rocks of distinctly older age than Cambrian. A part of these may be regarded as Dharwar in age, but owing to the complicated folding and inversions of the strata, it is not easy to identify the representatives of the Dharwar from younger sediments, much less to correlate and group together the widely-separated outcrops of these formations in the different parts of the Himalayas. One of the most important occurrences of these ancient sediments is in the neighbourhood of Simla, covering large tracts to its east and west, and known under the general name of the *Simla system* The lower part of this, composed of slates and quartzites, is regarded as Dharwar in age. Similar occurrences of slates, limestones, and quartzites resting unconformably on gneisses near Garhwal, in Central Himalayas, are recognised under the name of the *Jaunsar series* In the eastern Himalayas, a series of schists of the same formation near Darjeeling constitutes the *Daling series* Among the constituent rocks of the foregoing Himalayan series there are a few of the characteristic types of the Peninsular Dharwars, by which they are distinguished as such.

Himalayan Dharwars.

Homotaxis of the Dharwar system.

With regard to the age of the Dharwar system, there is no doubt that they are far older than the Cambrian, separated from them by an immense interval of geological time. With regard to their lower limit, they are so closely associated and intermixed with the Archaean gneisses at certain places that they leave no doubt that some of the gneisses are younger than some of the Dharwar schists. From their field-relations, and from the circumstance of a widespread unconformity separating the Dharwars from all younger formations, Sir T H. Holland has grouped them along with the Archaean. There is no parallel system of deposits comparable to the Dharwars in England or many parts of Europe, but the Dharwars show a

great degree of affinity with the Huronian rocks of America in their stratigraphic position and their petrological constitution.

[A very careful and detailed investigation has been made in the great Archaean complex of South India by the Mysore State Geological Department. The Mysore geologists have unravelled a number of successive eruptive groups in what have been hitherto described as the Archaean fundamental gneisses of the Peninsula, and as a result of these investigations they have come to the

(about 1/90 natural size)

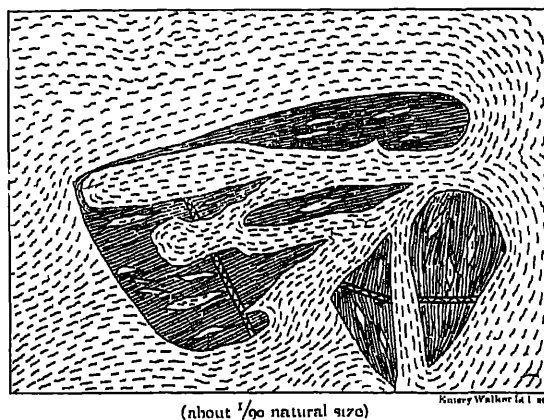



FIG 4.—Diagram showing the relation of Dharwar schists with the gneisses. (After Sampat Iyengar, *Rec M G D*, vol xi)

somewhat startling conclusion that the Dharwar schists are *all* decidedly older than the gneisses; that they are not of sedimentary origin as hitherto held, but are certainly in part and possibly entirely of igneous volcanic derivation, being in fact strictly basic lava-flows metamorphosed into hornblende and chloritic schists. In their field-relations the Dharwar schists have again and again been observed to show a distinct intrusive contact towards the invading gneisses, and have been penetrated by the latter times without number. The characters of the schists also, according to these observers, point to an igneous, and not a sedimentary origin, for they have not been able to trace any passage of these schists into phyllites or unaltered slates, within the territories of the Mysore State, which encompass an area of nearly 30,000 square miles. On the other hand, they show a gradual transition into epidiorites or hornblende-rocks. Many of the Dharwar conglomerates, likewise, are believed to be of crushed, *autoclastic*, origin. (Fig. 4 gives an idea of the nature of the association of the two rock-groups.)]

The subject is still one of the major controversies of Indian Geology, but the views of Dr. L. L. Fermor, formulated after his prolonged study of the South Indian crystalline complex, extending from 1902, have helped to clear it considerably. His conclusions tend to support the Mysore view in so far as the age of the main body of the Dharwars is concerned, though his work in extra-Mysore areas equally supports the older views as regards the sedimentary nature and origin of a portion of these rock-bodies, he entertaining little doubt about the detrital nature of the phyllites and quartzites.

The following general scheme of classification of the Archaeans of India is adopted from his published papers

4. The Charnockite and Bundelkhand Gneisses, with intrusions such as Peridotites, Granites and Syenites.
3 Re-melted masses of the Basement Gneiss, now constituting much of the schistose and garnetiferous Bengal and Peninsular Gneisses. These include some paragneisses and schists
2. Dharwar sediments and contemporaneous lavas ; also Khondalites
1 The oldest Basement Gneisses representing, in part at least, the primitive crust of the Earth.

Economics. The Dharwar system carries the principal ore-deposits of the country, *e.g* those of gold, manganese, iron, copper, tungsten, lead, etc These with their associated rocks are also rich in such industrially useful products as mica, corundum, etc , rare valuable minerals like pitchblende and columbite, etc. ; a few gems and semi-precious stones like the ruby, beryl, chrysoberyl, zircon, spinels, garnets, tourmalines, amethyst, rock-crystal, etc. This system is also rich in its resources of building materials, *e.g.* granites, marbles, ornamental building stones, and roofing slates The famous marbles of which the best specimens of ancient Indian architecture are built are a product of the Dharwar system

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References to the Dharwar system and its relation to the Archaean of the Peninsula are most plentiful in the Records of the Mysore State Geological Department See Smeeth, Bulletin III. M G.D. 1910, also J.A.S.B. vol. xi. (New Series), 1916.

CHAPTER V

THE CUDDAPAH SYSTEM

General

THE closing of the Dharwar era must have witnessed earth-movements on a very extensive scale, which folded the Dharwar sediments into complicated wrinkles, creating a number of mountain-ranges, the most prominent among them being the mountain-chain of the Aravallis. No such powerful crustal deformation, of equal degree of magnitude, seems to have taken place since then in the Peninsula, since all the succeeding systems show less and less disturbance of the original lines of stratification and of their internal structures, till, at the end of the Vindhyan era, all orogenic forces utterly disappeared from this part of the earth.

Cuddapah system.

A vast interval of time elapsed before the next rock-system began to be deposited, during which a great extent of Dharwar land, together with its mountains and plateaus, was cut down to the base-level by a cycle of erosion For it is on the deeply denuded edges of the Dharwar rocks that the basement strata of the present formation rest. This formation is known as the Cuddapah system, from the occurrence of the most typical, and first-studied, outcrops of these rocks in the district of Cuddapah in the middle of the Madras Presidency The Cuddapah is a series of formations or systems, rather than a single system, it being composed of a number of more or less *parallel* series or groups of ancient sedimentary strata, each of the thickness and proportion of a geological system by itself. They rest with a great unconformity, at some places on the Dharwars and at other places on the gneisses and schists, and themselves underlie with another unconformity the immediately succeeding Vindhyan system of Central India.

Lithology of the Cuddapahs.

This system is mainly composed of much indurated and compacted shales, slates, quartzites, and limestones. The shales have acquired a *slaty cleavage*, but beyond that there is no further metamorphism into phyllites or schists; such secondary minerals as mica, chlorite, andalusite, staurolite, garnets, etc., have not been developed in them; nor are the limestones recrystallised into marbles, as in the Dharwar rocks. Quartzites, which are the most common rocks of the system, are metamorphosed sandstones, the metamorphism consisting of the introduction and deposition of secondary silica, in crystalline continuity with the rolled quartz-grains of the original sandstone Contemporaneous volcanic action prevailed on a large scale during the lower half of the system, the records of which are left in a series of bedded traps (lava-flows) and tuff-beds. (See Fig 5.) Besides the above rocks, the Lower Cuddapahs contain brilliantly coloured and banded cherts and jaspers and some interstratified iron- and manganese-ores, very much like those of the Dharwar system. In these two peculiarities, most noticeable in the lower part, therefore, the Lower Cuddapahs resemble the Dharwar system; while the upper half, in its unmetamorphosed shales and limestones, shows a close resemblance to the overlying Vindhyan rocks.

On account of the absence of any violent tectonic disturbance of the Peninsula during later ages, the Cuddapah rocks have in general low angles of dip, except towards the Eastern coast, where they form a part of the Eastern Ghats (the Yellaconda range of hills), and where consequently they have been subjected to much plication and overthrust. To account for the enormous thickness of the Cuddapah sediments, which amounts to more than 20,000 feet in the aggregate, of slates and quartzites, it is necessary to suppose that a slow and quiet submergence of the surface was in progress all through their deposition, which lowered the basins of sedimentation as fast as they were filled.

Absence of fossils in the Cuddapahs

The entire series of Cuddapah rocks are totally unfossiliferous, no sign of life being met with in these vast piles of marine sediments. This looks quite inexplicable, since not only are the rocks very well fitted to contain and preserve

some relics of the seas in which they were formed, but also all mechanical disturbances, which usually obliterate such relics, are absent from them. It cannot again be surmised that life had not originated in this part of the world, since in formations immediately subsequent to the Cuddapahs, and in areas not very remote from them, we find evidence of fossil organisms, which, though the earliest animals to be discovered, are by no means the simplest or the most primitive. The geological
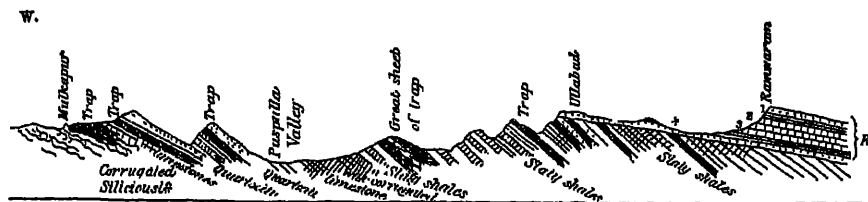
FIG. 5—Sketch section illustrating the relation of Cuddapah and Kurnool rocks, marked (K)
After King, *Mem.* vol viii 1872

record is in many respects imperfect, but in none more imperfect than this—its failure to register the first beginnings of life, by far the most important event in the history of the earth

Classification

The Cuddapah system is divided into two sections, an upper and a lower, separated by a great unconformity. Each of these divisions consists of several well-defined series, whose stratigraphic relations to each other, however, are not definitely established, and which may be quite parallel or homotaxial to each other instead of successional

Upper { Nallamalai Series, 3400 ft | Kistna Series, 2000 ft | Kaladgi Series, 10,000 ft.

Unconformity.

Lower { Bijawar Series,
Cheyair Series (10,500 ft.) and
Gwalior Series, with a
Basic Volcanic Series.
Papaghani Series (4500 ft.).

Distribution.

A large development of these rocks occurs in the type area of Çuddapah district. The outcrop is of an irregular crescent shape, the concave part of which faces the coast, the opposite

side abutting on the gneisses. Another large development of the same system is in the Central Provinces and in Chhatisgarh. A few isolated exposures occur in the intervening area, while to the north-west they occur on the east border of the Aravallis. A part of the zone of metamorphosed sediments lying to the south of the central crystalline axis of the Himalayas can be referred to the Cuddapah system of rocks, but they cannot be certainly identified as such, as in the case of the representative of the Dharwar and the succeeding Vindhyan

The Lower Cuddapah.

The Papaghani series. The lowest member of the Cuddapah system takes its name from the Papaghani river, a tributary of the Penner, in the valley of which these rocks are exposed. The bottom beds are sandstones followed by shales and slates, with a few limestone layers in the shales. Contemporaneous lava-flows, with intrusions of the same magma in the form of dykes and sills, are common; in the latter case, where the invading rock comes in contact with limestones, the latter are found to be converted into marbles, serpentines, and talc.

The Delhi series of strata referred to in the last chapter is probably of Lower Cuddapah age, though in its intense structural disturbance and degree of folding it departs from the general tectonic features of this system It appears to be a locally specialised type of the Cuddapahs owing its structural disturbance to local orogenic flexures and also to the intrusion of large bodies of granite and amphibolite The Delhi series occupies a large extent of E Rajputana country extending some 200 miles south of Delhi. Over the whole of this area it exhibits violent unconformity with the Aravallis at its base, while towards the newer Vindhyan terrain to the east its relations are those of a great boundary fault, with a throw of over 5000 ft. Dr. A. M. Heron has classified the Delhi series as follows:

Delhi System	*Ajabgarh* series: slates, phyllites, quartzites and impure limestones, . . .	5000 ft
	Hornstone breccia of variable thickness.	
	Kushalgarh limestone, ...	1500 ft.
	Alwar series: quartzites, arkose, conglomerates and mica-schists with bedded lavas, . .	10,000–13,000 ft.
	Raialo limestones, quartzites and dolomites, .	2000 ft.
Unconformity.	~~~~~~~~~~~~	
Aravalli Series	Mica-schists, marbles, quartzites and schistose conglomerates with granite and amphibolite intrusions.	

The Bijawar series

The upper division of the Lower Cuddapah is more widely developed, and occurs extensively at Bijawar, Cheyair, Gwalior, etc. The Bijawar series is composed of cherty limestones, siliceous hornstones and ferruginous sandstones, haematite beds, and quartzites, resting unconformably on the gneisses. But the most distinctive character of the Bijawar series is the presence in it of abundant products of contemporaneous volcanic action—ash-beds, lava-flows and sills of a basic augite-andesite or basalt, now resting as a number of interbedded green traps. The dykes of these lavas that have penetrated the older formations are supposed to be the parent-rock of the diamonds of India The reputed "Golconda" diamonds were mostly derived from a conglomerate mainly composed of the rolled pebbles of these dykes Wherever the andesitic lava of the Bijawar series is subjected to folding and compression, it has altered into an epidiorite.

An exposure of very similar character, occurring in the valley of the Cheyiar river, is known as the *Cheyair series*, while the one at Gwalior, on which the town of Gwalior stands, forms the *Gwalior series*. In the latter series there is a very conspicuous development of ferruginous shales, jaspers, porcellanites, and hornstones, associated with the andesitic or basaltic lavas of Bijawar The porcellanite and lydite-like rocks appear to have originated from the effects of contact-metamorphism on argillaceous strata, while the preponderance of hornstones, cherts and other siliceous rocks points to the presence of solfataric action, connected with the volcanic activity of the period. Solfataras or hot siliceous springs come into existence during the declining stages of volcanoes, they precipitate large quantities of silica on the surface, likewise bringing about a good deal of *silicification* of the previously existing rocks by chemical replacement (metasomatism) in the underlying rocks The lower division of the Gwalior series, resting upon the basement gneiss, is known as the Par, and the upper is designated the Morar series

An outlier formed of identical rocks is seen in the valley of the Pranhita, and is named *Penganga beds*. It must be understood that the reason for giving these different local names to the different occurrences of what might ultimately prove to be the same division of the Lower Cuddapah is the uncertainty, which is always present in the case of unfossiliferous strata, of correlating them to one another in the absence of any positive evidence. Such an arrangement is, however, only provisional, and is adopted by the Geological Survey in their

explorations of new districts till the homotaxis of the different exposures is clearly established. The local names are then dropped, and all the occurrences designated by a common name

The Upper Cuddapahs.

The UPPER CUDDAPAHS rest unconformably over the rocks last described at a number of places. The most important development is in the type area of the Cuddapah basin, where it has received the name of the *Nallamalai series*, from the Nallamalai range of hills in which it is found. The component rocks of the *Nallamalai series* are quartzites (Bairankonda quartzites) at the lower part, and indurated shales and slates (Cumbhum slates) in the upper. In the limestone beds that occur intercalated with the shales there is found an ore of lead, galena.

The Kaladgi series.

The *Kaladgi series*, another member of the same system, is several thousand feet of quartzites, limestones, shales and breccias, occupying the country between Belgaum and Kaladgi. Towards the west they disappear under the Deccan basalts of Cretaceous age. The upper part includes some haematite-schists, which include sometimes so much of haematite as to constitute a workable ore of iron. Besides the above there are other localities where rocks of the Upper Cuddapah horizon occur, viz in the Kistna valley (the *Kistna series*), in the Godavari valley (the *Pakhal series*, of 7500 feet of quartzites, slates and flinty limestone), and in Rewah.

Economics.

The economic importance of the Cuddapah rocks lies in some iron and manganese-ores, interbedded with the shales and slates Other products of some use are the bright-coloured jaspers and cherts, which are used, when polished, in interior decoration and inlaid work, as in the old Mogul buildings.

Stratigraphic position.

The stratigraphic relations of the Cuddapahs prove that they are far younger than the Dharwar. On the other hand, their thoroughly azoic nature, and the moderate degree of metamorphism they have undergone, show that the Cuddapahs are older than the Vindhyan In their lithological characters they show much resemblance to the pre-Cambrian Algonkian system of North America. In Holland's scheme of classification, as we shall see later on, the Cuddapahs are grouped with the overlying Vindhyans as the *Purana group* .

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CHAPTER VI

THE VINDHYAN SYSTEM

Extent and thickness

THE Vindhyan system is a vast stratified formation of sandstones, shales and limestones encompassing a thickness of over 14,000 feet, developed principally in the Central Indian highlands which form the dividing ridge between Hindustan proper and the Deccan, known as the Vindhya mountains They occupy a large extent of the country—a stretch of over 40,000 square miles—from Sasaram and Rhotas in Western Behar to Chitorgarh on the Aravallis, with the exception of a central tract in Bundelkhand The outcrop has its maximum breadth in the country between Agra and Neemuch

Rocks

The Vindhyan system is composed of two distinct facies of deposits, one calcareous and argillaceous, characteristically developed in the lower part, and the other almost exclusively arenaceous, forming the upper system. The shale, limestone and sandstone strata show very little structural displacement or disturbance of their primeval characters; they have preserved almost their original horizontality of deposition over wide areas; the rocks show no evidence of metamorphism, as one is led to expect from their extreme age, beyond induration or compacting The shales have not developed cleavage nor have the limestones undergone any degree of crystallisation. The only locality where the Vindhyan strata show any marked structural disturbance is along the south-east edge of the Aravalli country, where they have been affected by folding and overthrust due to the crust-movements which succeeded their deposition, and their internal mineral structure considerably altered, especially in the case of the freestones which have become quartzites. The epeirogenic upheaval which lifted up the

Structural features

Vindhyan deposits from the floor of the sea to form a continental land-area was the last serious earth-movement recorded in the history of the Peninsula, no other disturbance of a similar nature having ever affected its stability as a land-mass during the long series of geological ages that we have yet to review. The Peninsula has remained an impassive solid block of the lithosphere, unsusceptible to any folding or plication, and only affected at its fringes by slight movements of secular upheaval and depression

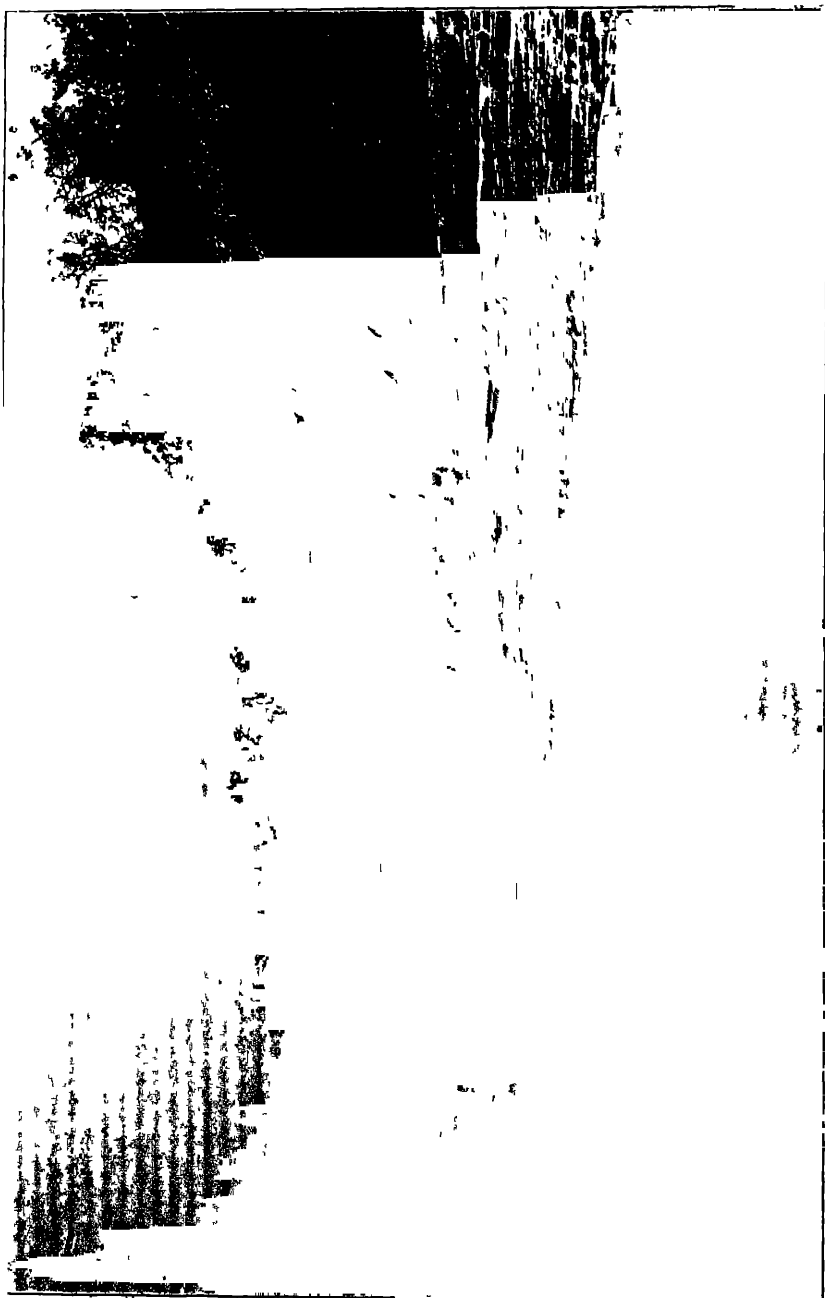
The Vindhyan sandstones throughout their thickness give evidence of shallow-water deposition in their oft-recurring ripple-marked and sun-cracked surfaces, and in their conspicuous current-bedding or diagonal lamination, characters which point to the shallow agitated water of the coast, and the constantly changing velocity and direction of its currents.

Life.

Except for a few obscure traces of animal and vegetable life occasionally discernible in the Vindhyan system, and such plausible evidences of the existence of life as are furnished by the presence of thick limestone strata and beds of carbonaceous shales, this vast pile of sandstones, shales and limestones is characterised by an almost total absence of recognisable organic remains The only animal fossils that have been hitherto discovered in these rocks are a few discs, the remains of some primitive *brachiopoda* (?), embedded in the lower part of the Bhander series, discovered by Mr. H. C. Jones near Neemuch But the specimens are too imperfectly preserved, and of perhaps embryonic stage of development, to permit of their specific determination. *Fucoid* markings, belonging to indistinguishable *thallophytic* plants, are usually seen on the ripple-marked and sun-cracked surfaces of sandstones and shales.

Classification.

The Vindhyan system falls into two natural divisions, which, though of very unequal proportions, have been determined by important physical considerations. They are separable as much by an unconformable junction between the two divisions as by the sharp lithological contrast between them.

The difference in petrological characters denotes a fundamental difference of physical geography, viz. the prevalence of a deep sea during the earlier history of the formation, and its shallowing at the time when the upper part of the system was deposited. A great change must have taken place simultaneously in the areas which furnished the sediments.

UPPER REWAH SANDSTONE, RAHUTGARH, SANGOR DISTRICT.

	Series	*Stages*
Upper Vindhyan	*Bhander*	Upper Bhander sandstone Sirbu shales Lower Bhander sandstone Bhander limestone
	Conglomerate-bed	
	Rewah.	Upper Rewah sandstone. Jhiri shales. Lower Rewah sandstone Panna shales
	Conglomerate-bed	
	Kaimur	Upper Kaimur sandstone. Kaimur conglomerate. Bijaigarh shales. Lower Kaimur sandstone.
Unconformity.		
Lower Vindhyan.	*Kurnool Series* *Bhima Series,* etc.	Limestones and calcareous shales.
	Malani Series of ryolites and tuffs	
	Granite bosses of Jalor and Siwana.	

Distribution of the Lower Vindhyan

The most typical, and at the same time the most conspicuous, development of the system is along the great series of escarpments of the Vindhyan range, from which the system takes its name. The lower division is well displayed in the Son valley, in Chhatisgarh and in the valley of the Bhima At the latter locality they constitute the *Bhima series,* composed of quartzites and grits in the lower part and shales and limestones of varying colours in the upper Resting unconformably over the Cuddapah system, in the district of Kurnool, there is a large outcrop of Lower Vindhyan rocks, about 1200 feet in thickness, known under the name of the *Kurnool series* (Fig. 5). The Kurnool series is interesting, as it contains at the base a group of sandstones, some bands of which are *diamondiferous* These beds, known as the *Banaganapalli beds,* consist of coarse, earthy felspathic or ferruginous sandstones of a dark colour. North of the Narbada, the Lower Vindhyans are very well exposed in the Dhar forest area. The Sullavai sandstones of the Godavari valley are a group of Lower Vindhyan sandstones and quartzites resting unconformably on the Pakhal quartzites The composition of all these occurrences shows local variations

in the rock-types, but in the main conforms to the argillaceous and calcareous nature of the system. Some of the limestones show a concretionary structure, the concentric layers exhibiting different colours and giving to the polished rock a beautiful marble-like appearance. The limestones of the Lower Vindhyan formation are extensively drawn upon for burning as well as for building purposes. The Rohtas limestone of the Shahabad district is especially valuable for lime and cement manufacture, and is largely quarried

The Lower Vindhyan rocks of Western Rajputana deserve special notice. They show there a very much altered facies, being composed of a group of rhyolitic lavas with abundant pyroclastic material, resting unconformably on the Aravalli schists. This volcanic series is known as the *Malani series*, from the State of that name (near Jodhpur in Marwar). The Malani rhyolites cover many thousands of square miles around Jodhpur. They are partly glassy, much devitrified, amygdaloidal lavas largely interstratified with tuffs and volcanic breccia. The lavas vary in acidity from rhyolites to quartz-andesites. In the majority of cases they have undergone such an amount of devitrification that they appear almost as felsite, the glassy ground-mass having completely disappeared. An outcrop of the Malani series composed of felsitic rhyolites and tuffs occurs, remote from the Aravallis, in the plains of Northern India, in the Sangla hill in the Punjab, a small highly eroded outlier of the Aravalli chain.[1]

The Malani series.

Connected with these lava-flows, as their subterranean plutonic roots or magma-reservoirs which supplied the materials of the eruptions, are bosses of granite, laid bare by denudation, in some parts of Rajputana. Two varieties of granite are recognised in them—one, hornblende-biotite-granite (*Jalor granite*), and the other, hornblende-granite (*Siwana granite*). The latter boss shows distinctly intrusive relations to both the Malani series and the Aravalli schists; it rises to a height of nearly 3000 feet above sea-level.

Meaning of 'Lower" and 'Upper" Vindhyan.

The Lower Vindhyan is separated from the upper by a very pronounced unconformity This signifies that earth-movements supervened after the deposition of the Lower Vindhyan

[1] *Rec. G S.I* .vol xliii pt. 3, 1913

sediments which elevated them into land and put a stop to further sedimentation in these areas. When, after re-submergence, deposition was renewed, an interval of time had elapsed, during which the former set of conditions disappeared, and the mountains and highlands which yielded the detritus changed completely. Such earth-movements, causing cessation of deposition in a particular area, with a change in the physical conditions, are at the root of stratigraphic divisions Smaller and more local breaks in the continuity of the Upper Vindhyan succession have led to its further sub-division into *series* and *stages* While profounder changes, accompanied by more pronounced alterations of land and sea, affecting the inter-continental and inter-sea migrations of life inhabiting them, determine the limit between *system* and *system*

Upper Vindhyan.

In their type-area, north of the Narbada, the Upper Vindhyan sandstones consist of three well-marked divisions (series) ·

Bhander Series - -	Upper Bhander sandstone. Sirbu shales Lower Bhander sandstone. Bhander limestone. Ganurgarh shales
Diamondiferous beds	
Rewah Series - -	Upper Rewah sandstone Jhiri shales. Lower Rewah sandstone. Panna shales.
Diamondiferous beds.	
Kaimur Series - -	Upper Kaimur sandstone. Kaimur conglomerate. Bijaigarh shales. Lower Kaimur sandstone.

The East India Railway from Katni to Allahabad runs through the heart of the Vindhyan country and thence up to Dehri-on-Son, passes along its north-eastern margin, without ever leaving sight of the outcrops of horizontally bedded red or buff sandstones. Another Vindhyan province lies in Central India, and on the eastern borders of the Aravalli chain. This country is also crossed by the railway from Jalra Patan to Bharatpore, which almost constantly keeps within sight

the Central and the younger rocks of the Outer Himalayas. They are designated by various names in the different parts of the mountains. Near Peshawar they form a large outcrop (the *Attock series*), of dark slates, with a few limestones and sandstones here and there permeated with trappean intrusions, in Hazara also there is a large outcrop of black unfossiliferous slates. In the Simla area the Vindhyan horizon is probably recognised in a thick series of black, carbonaceous shales, limestones and quartzites, which have been classified into three divisions—in the ascending order, the *Blaini series*, the *Infra-Krol* and the *Krol series* The first-named series contains along with the other components a boulder-bed in which rounded and angular boulders, some of them "facetted" and striated by ice-erosion, are embedded in a matrix of fine slate. The boulders suggest the agency of floating ice, which dropped them while the material of the slate was being deposited. Overlying it is a thick series of carbonaceous slates—the Infra-Krol series. This in turn is overlaid by limestones and quartzites (Krol series), conspicuous on the mountains around Simla North of Chakrata, rocks of this age, forming the peak of Deoban, are known as the *Deoban series* They consist of extremely compact grey dolomite and limestones with cherty concretions. Near Darjeeling they constitute the *Baxa series* of quartzites, slates and dolomites. All these Vindhyan rocks of the Himalayas are distinguished from the Vindhyan of the Peninsula by the scanty development in them of the arenaceous facies and the predominance of limestones and shales; also, as is quite obvious, they are much folded, compressed and inverted by being involved in the severe flexures of the mountains.

The relation of the Himalayan unfossiliferous systems to the Peninsular Puranas.

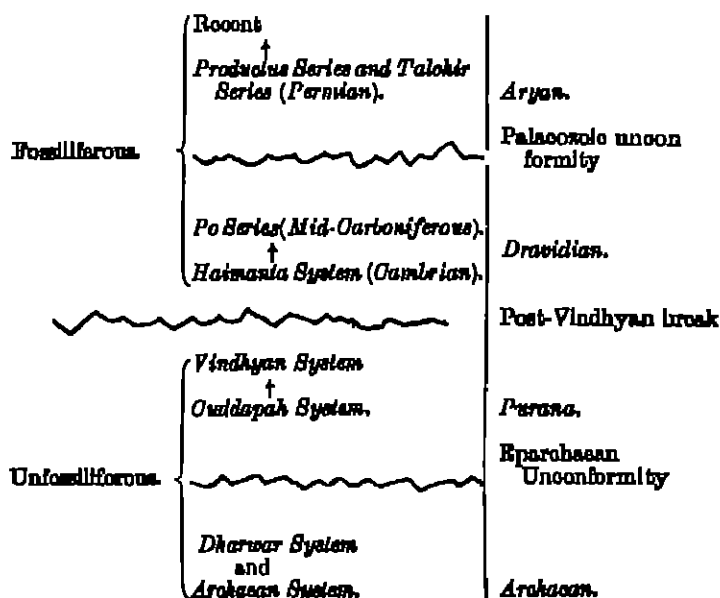
It is the belief of the Indian Geological Survey, first promulgated by Sir T H. Holland, that these old unfossiliferous formations developed on the south of the central Himalayan axis, representing the Dharwar, Cuddapah and Vindhyan systems of the Peninsula, are only the northern outliers or prolongations of the respective Peninsular systems, which were once continuous and connected before the Himalayan area became demarcated from the Peninsula by the upheaval

of the Himalayan chain and the concomitant formation of the deep Indo-Gangetic depression. During these movements the extra-Peninsular extensions of the Dharwar, Cuddapah and Vindhyan systems were caught up in the Himalayan system of flexures, while their "Peninsular congeners" were left undisturbed The belief receives strong confirmation from the fact that on the northern side of the central axis, viz the Tibetan, there is an altogether different sequence of strata from that occurring on the Indian side, being composed of marine fossiliferous sediments of almost every geological age from the Cambrian to the Eocene. This total difference in the facies of the deposits of the two sides of the chain suggests the prevalence of altogether different physical and geographical conditions in them, and indicates that the two areas (Tibet and India) were from the earliest times separate and underwent an altogether different geological history.

Homotaxis. With regard to the homotaxis of the Vindhyan system there exists some difference of opinion. From its lithological agreement with the fossiliferous Cambrian of the Salt-Range, Mr. Vredenburg of the Indian Geological Survey has considered them to be Cambrian in age. Sir T. H. Holland, however, regards all the unfossiliferous Peninsular formations resting above the Archaean-Dharwar complex as pre-Cambrian, occupying much the same position as the Torridon sandstone of Scotland, overlying the Lewisian gneisses, and groups them in his *Purana group.* The Purana group of this eminent author includes the unmetamorphosed but more or less disturbed and folded rock-system that intervenes between the crystalline Archaean and the fossiliferous younger systems of the Peninsula The Purana group thus forms a sort of transition between the foliated and the highly metamorphosed Dharwar and Archaean gneisses and the fossiliferous Palaeozoic strata. They include the major part of what, in the early days of Indian geology, was called the *Transition System.*

We have seen in Chapter IV. that the same author has linked the Dharwar with the Archaean system, recognising, in the unconformity that separates the former from the

time than in that which separates the Archaean from the Dharwars.

The following table shows in outline Holland's scheme of classification of the Indian formations. His classification of the post Purana systems is based upon the recognition of the two most profound breaks in the continuity of that series of deposits. These breaks or "lost intervals" have a fundamental meaning in the geological history of India; they denote periods of great crust movements, and mark the commencement of new areas of life and sedimentation. The first break was subsequent to the Vindhyans and is universally observed in both the Peninsula and the extra-Peninsula. The other is a somewhat less pronounced break at the base of the Permian in the extra-Peninsula. In all the other areas of India, the post-Vindhyan break is the most momentous and universal, and comprehends a long cycle of unchronicled ages from the Vindhyan to the Permo-Carboniferous.

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CHAPTER VII

THE CAMBRIAN SYSTEM

The Cambrian of India.

MARINE fossiliferous rocks of Cambrian age are found in a thick series of strata at two places in the extra-Peninsula, each of which deserves a separate description The first and the most easily accessible locality is the Salt-Range in the north-west Punjab, the other is the remote district of Spiti in the northern Himalayas, in the province of Kumaon, lying north of the Simla mountains, beyond the crystalline axis of the Himalayas. These rocks contain well preserved fossils, and hence their age is no longer a matter of conjecture or hypothesis, as was the case with the Peninsular formation hitherto dealt with.

The Salt-Range.

[The Salt-Range is the most important locality in India, for the study of physical as well as stratigraphical geology Since very early times it has attracted the attention of geologists, not only because it contains a very large portion of the fossiliferous stratified record of the Indian region, but because of the easily accessible nature of the deposits and the clearness with which the various geological formations are exposed in its hills Besides the stratigraphical and palaeontological interest, there is inscribed in its barren cliffs and dried gullies such a wealth of geo-dynamical and tectonic illustrations, that this imposing line of hills can fitly be called a field museum of geology The Salt-Range is a continuous range of low, flat-topped mountains rising abruptly out of the flat Punjab plains. The range extends, from long 71° E to 74° with an approximately east-west strike from the Jhelum westwards, through the Indus, to a long distance beyond it, undergoing where it crosses the Indus a deep bend of the strike to the south west In all essential structural stratigraphical as well as physiographic features the Salt Range offers a striking contrast to the north western portion of the Himalayas, which rise hardly fifty miles to north of it The two mountain ranges thus belong to a different orographic system altogether The prominent structural peculiarity of the Salt-Range is the more

other northern side inclining gently towards and merging
o high Potwar plains, which lie between Jhelum and
indi The general dip of the strata is to the north direc
m one end of the range to the other Thus, it is on the
order that the youngest Tertiary rocks of the mountains
, inclining away from the steep escarpment, while it is in
eep escarpments that the oldest Palaeozoic formations are

The line of high precipitous cliffs is intersected by a
of deep gullies and ravines, some of them deserving the
f cañons, affording the clearest sections, which distinctly

FIG 7 —Section illustrating the general structure of the Salt-Range (Block-faults). Section over Chambal Hill (East).

e. Dolomite bed in Salt-marl.

		Feet.
k No. 13	Grey sandstones, very friable, and light brown marly clays; maximum apparent thickness which may be much below the real amount	3,600
	Red zone chiefly clays	1,500
No 12	Lower sandstone etc.	500
mbrian)	4 Magnesian sandstone	50 to 0
	3 Dark shaly band	150 to 100
	2. Purple sandstone	500
	1 Red gypseous marl	?

emoirs. Geo Survey of India, vol. xiv

he inner architecture of the range, as well as all the details
ratigraphy There is no vegetation, or any covering of
osed rock or soil to hide the slightest detail of these

Extensive heaps of talus or scree-deposits are seen all
e southern foot of the range at the base of the bold bare

ntire length of the range is faulted in a most characteristic
by a number of transverse dip-faults into well marked
block-structure) (Fig 7) These clean-cut faulted blocks
onspicuous to one who looks at the range from the plains,
y can be separated out, and the main elements of their
tion recognised from great distances. At many places the
s of the *reversed* type, sometimes intensified into thrust-
which have introduced a great deal of complication into
cture and stratigraphy of the area. (See Figs 7, 8, 12

[illegible]
common salt, all throughout its extent In this way an immense quantity of rock salt is embedded and available for extraction in all parts of these mountains.]

ult- ian. At the eastern extremity of the Salt Range a thick stratified series of rocks occurs in a conformable sequence They are sub-divided into the following groups in the order of superposition (Fig 7)

Salt-pseudomorph shales : 450 ft.	Bright red or green flaggy argillaceous beds, with cubic clay pseudomorphs of salt-crystals.
Magnesian-sandstone : 250 ft.	Laminated white or cream coloured sandstones, often dolomitic.
Neobolus shales : 100 ft.	Grey or dark coloured shales containing brachiopods, trilobite gastropods, etc
Purple sandstone : 450 ft.	Red or purple sandstones with few beds of shale.
Salt-marl : 1500 ft. ?	Loose red earth or marl containing abundant gypsum and salt; unstratified

Salt- The lowest, salt-marl, is a curious earthy or clayey deposit called "Marl" because of its containing carbonates of lime and magnesia, and "Salt-Marl" because of the existence within it of thick beds and lenses of nearly pure common salt, sodium chloride. It is a loose earthy formation, of a brick red colour, containing abundant gypsum in beds and irregular masses and some dolomite in layers and fragments The whole formation is quite exceptional in not showing any trace of stratification either in the marl itself or in the contained gypsum, its base is not seen and its top shows quite anomalous relations to the overlying strata.

Near Khewra, the accumulation of gypsum and rock-salt is on a large scale At the Mayo Salt-Mines, at Khewra, there is a mass of nearly pure crystalline salt of a light pink colour, interbedded with some seams of impure red earthy salt (*Kalar*), of the total thickness of 300 feet Above this is another bed of the thickness of 250 feet. The upper deposit is not so pure as the lower, because of its containing more intercalations of Kalar and other dissolved salts, viz. calcium sulphate and

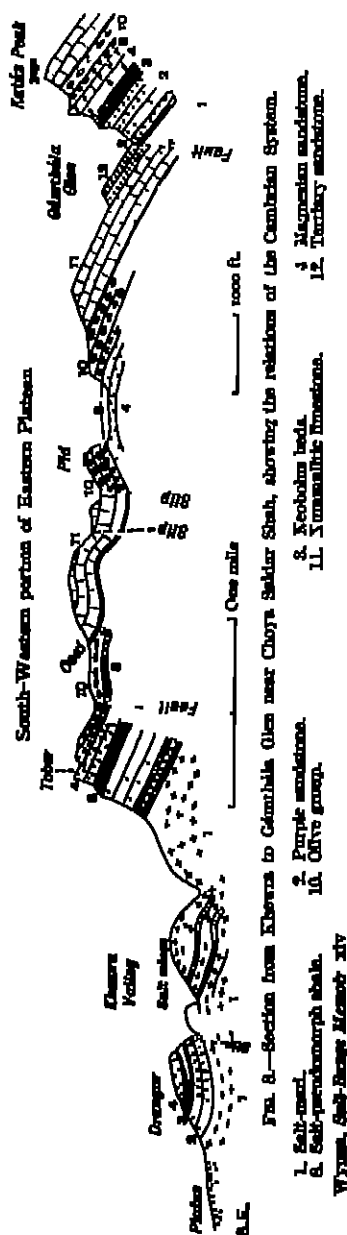
n chloride, in greater
tions. The lateral
ion of the salt-beds
rs to be very great,
nting to several square
in area, and thus the
quantity of this highly
mineral, at Khewra
is believed to be prac
inexhaustible. To
ust be added the huge
and pockets of salt
ned in the red marl
or parts of the range,
worked in several
r mines. The associ
ypsum is also in large
s, it shows much
ion in purity and in
of its hydration At
it passes into an
e by dehydration It
an irregular bedding
rmation, but it pos
no definite relations
salt-beds, as a rule
ing them, but often
ing below them as

ORIGIN of *salt-marl* is
nown with certainty
ntire, at any rate ap-
, absence of stratifica
such an earthy deposit,
ular composition, its
lous relations to the
ing strata, the enor-
quantity of its enclosed
which could remain un

South-Western portion of Eastern Plateau

FIG. 8.—Section from Khewra to Gámthála Glen near Choya Saidan Shah, showing the relations of the Cambrian System.

1. Salt-marl. 2. Purple sandstone. 3. Neobolus beds. 4. Magnesian sandstone.
6. Salt-pseudomorph shale. 10. Olive group. 11. Nummulitic limestone. 12. Tertiary sandstone.

Wynne, *Salt-Range Memoir* xiv

dolomite—all these considerations negative the idea of the salt marl being a sedimentary deposit as such A far different origin has been ascribed to it It has been held by many geologists since Oldham that the entire salt-marl deposit is due to the thermo-metamorphism of some previously existing formation of unknown composition, by some hypogene agent giving off vapours of hydrochloric and sulphuric acids Dr R D Oldham has said, "It is not a hypogene rock intrusive in its present position, nor is it a sedimentary rock formed superficially as such with its associated gypsum and salt, but is due to the alteration of pre-existing sediments whose exact composition is unknown by the subterraneous action of acid vapours and solutions" The salt and gypsum, therefore, are believed to be due to the alteration induced by a subdued or modified volcanic agency of a later date

Of late, however Dr E H Pascoe has adduced evidence to prove that the apparent infra Cambrian position of the salt-marl is not its normal stratigraphical position, but that the salt and gypsum both of which he believes to be of sedimentary origin, together with their associated strata, are of Eocene age and their present position is brought about by an overthrust, or reversed fault, which has thrust the very much younger Tertiary rocks underneath the Cambrian strata, beginning with the purple sandstone. The structure of the range is one of extensive faulting as already mentioned often of the overthrust type and this interpretation appears probable, especially in view of the fact that another enormous outcrop of salt of a like character occurs at Kohat, only a few miles distant from the Salt Range, whose geological age is inferred as Tertiary on more satisfactory evidence (page 213) [1]

Observations by Dr Christie of the Indian Geological Survey has also led him to ascribe an ordinary sedimentary origin to the salt and gypsum. He is of the opinion that the salt and gypsum are due to the evaporation of sea-water in inland or enclosed basins which were intermittently cut off from the main ocean by barriers The red saline earth or Kalar-seams are held to indicate the last stage of the desiccation of the sea-bed, the occurrence of potassium-salts mentioned below, just underneath the latter, is pointed to as a further evidence in support of the evaporation theory, for, in a sea basin undergoing desiccation, the salts of potassium are the last to be precipitated, after nearly 98 per cent of the water has evaporated It is argued that the stratification planes which were originally present, both in the enclosing marl and in the salt, have been obliterated subsequently by superficial agencies as well as by the effects of compression and earth movements on a soft plastic substance like the marl The latter circumstance also accounts for the

[1] E. H. Pascoe, *Mem. G S I* vol. lx. pt. 3, pp. 352-371 (1920).

ween the two [1]]

The economic importance of the salt deposits is great as they produce about 150,000 tons of salt per year. Besides the chloride of sodium, there are found other salts, of use in agriculture and industries. Of the latter the salts of *Potassium* (Sylvite, Kainite, Blödite and Langbeinite) which occur in the underlying beds of red earthy salts (Kalar), are the most important. Magnesium salts are Epsomite, Kieserite and Glauberite.

Overlying the salt marl, but in a most irregular and unconformable manner, are a series of purple or red coloured sandstones. The junction plane between the two series of strata is so discordant that the marl appears to have intruded itself into the lower beds of the purple sandstone. The purple sandstone is a red or purple-coloured series of sandstone-beds. It is a shallow water deposit, as can be seen from the frequency of oblique lamination, ripple marks and sun-cracks, and such surface-marks as rain prints, worm burrows, fucoid impressions, etc. The lower beds are argillaceous, gradually becoming more arenaceous at the top. Worm tracks and fucoid marks are the only signs of life in these rocks.

This stage is succeeded by the most important beds of the system, a group of dark micaceous shales with white dolomitic layers, known as the *Neobolus beds*, from their containing the fossil brachiopod *Neobolus*. Other fossils are *Discinolepis*, *Lakhmina*, *Lingula*, *Orthis*, *Conocephalites*, *Redlichia* (a trilobite resembling *Olenellus*) and the doubtful mollusc, *Hyolithes*. The brachiopods and trilobites resemble those of the Cambrian of Europe, and hence the Neobolus beds stamp the whole connected series of deposits as Cambrian. This division of the Cambrian of the Salt-Range is well displayed in the hill surmounted by the old Gakkar fortress in the neighbourhood of Khewra.

Overlying the Neobolus beds is the magnesian sandstone stage, a sandstone whose matrix is dolomitic, and imparts to the rock its white or cream colour. There are also some beds

[1] *Rec. G.S.I.* vol. xliv, pt. 4, 1914

Economics

The purple sandstone.

Neobolus beds.

Magnesian sandstone stage.

Some of the beds in this group are very finely laminated. Sometimes a hundred laminae can be counted in the thickness of an inch. When showing oblique lamination and minor faulting in hand-specimens, they form prize specimens in a student's collection. The only fossil contained in these rocks is *Stenotheca*, a lower Cambrian mollusc, besides a few unrecognisable fucoid and annelid markings.

udo- shales. The Salt-pseudomorph shales are bright red and variegated shales with thin bedded sandstones. The name of the group is derived from the numerous pseudomorphic casts of crystals of rock-salt very prominently seen on the shale-partings. It is evident that these strata were formed on a gently shelving shore which was laid bare at each retreating tide. In the pools of salt-water left on the bare beach crystals of salt would be formed by evaporation, which would be covered up by the sediments brought by the next tide. The cavities left by their subsequent dissolution would be filled up by infiltrated clay.

THE CAMBRIAN OF SPITI

In the Spiti valley [1] lying amid the north eastern ranges of the Kangra district, and in some adjoining parts of the Central Himalayas a very complete sequence of fossiliferous Palaeozoic and Mesozoic strata is laid bare, in which representatives of all the geological systems, from Cambrian to Eocene, have been worked out in detail by a number of great geologists.

The Spiti area, the classic ground of Indian geology, which will recur often in the following pages, is in general a broad synclinal basin (a *Geosynclin*e) which contains the stratified deposits of the old Himalayan sea representative of the ages during which it occupied the northern Himalayas and Tibet.

The axis of the syncline is north west–south-east, in conformity with the trend of the Himalayas. The youngest Mesozoic formations are, obviously, exposed in the central part of the basin, while the successively older ones are laid

[1] The Spiti river is a tributary of the river Sutlej, running N.W.-S.E. in a tract of mountains which form the boundary between N.E. Punjab and Tibet. (Lat. 32° 10′ N. Long. 78° E.)

rards the Punjab The dip of the outer formations is rly in the main, i.e. towards the interior All these ions are fossiliferous, the fossils being the means of a recise correlation of these systems with those of Europe ident should consult Dr Hayden's *Memoir on the Geo- Spiti*[1] Hayden's researches have contributed a great elucidating the geology of this region—especially its zoic geology

The Cambrian of Spiti.

Cambrian of Spiti rests over the highly metamorphosed mbrian series of schists (the Vaikrita series), which in re underlain by the Archaean gneisses They are a hickness of highly folded and disturbed sedimentary omprising the whole of the Cambrian system—Lower, and Upper The system has been named *Haimanta*, s occurrence in high snow capped peaks The com rocks are principally siliceous and argillaceous rocks s slates and quartzites, the latter occupy the base, d by red and black slates, with much enclosed haematite former and carbonaceous matter in the latter At are again siliceous slates and shales interbedded with e. The upper portion of the group, constituting a ss of some 1200 feet, is fossiliferous A fairly abundant an fauna has been discovered in them, of which s form the chief element The following are the genera *Olenus, Agnostus, Microdiscus, Ptychoparia* species) and *Dicellocephalus* Among the other fossils brachiopods *Lingulella, Obolus* and *Obolella*, and a noids and gastropods (*Bellerophon*) The species of ve named genera of fossils show clear affinities with opean Cambrian forms

Cambrian fossils.

most complete development of these strata is exposed valley of the Parahio, a tributary of the Spiti river g. 9, p 90)

Autoclastic conglomerates.

conglomerate layers among the slates are of interest of their uncommon mode of origin They are not y clastic conglomerates of sedimentary derivation, cording to Dr Hayden, they are of "autoclastic"

[1] Vol. xxxvi pt. 1 1904

quartz into more or less rounded fragments or lenticles scattered in a fine-grained micaceous matrix, representing the original material of the veins

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CHAPTER VIII

HE SILURIAN, DEVONIAN AND LOWER CARBONI FEROUS SYSTEMS

General

ɜ great groups of Palaeozoic strata do not occur at all in enmsular part of India, while their occurrence in the Penmsular area also, with one exception, is outside the ɪphical limits proper of India, and confined to the northern borders of the Himalayas and to Upper Burma. In the sula there exists, between the Vindhyan and the next ing (Upper Carboniferous) deposits, a great *hiatus* arising ɪ persistent epeirogenic uplift of the country during the hat followed the deposition of the Vindhyan sediments bsence from India of these formations, constituting three-fourths of the Palaeozoic history of the earth, is noteworthy, as it imparts to the Indian geological record, ally of the Peninsula, a very imperfect and fragmentary ter The Himalayan occurrences of these rock groups, d to above, are restricted also to the northernmost or n zone of the Himalayas, where a broad belt of marine erous sedimentary rocks extends from the western ity, Hazara and Kashmir, through Spiti, Garhwal and un, to Nepal and even beyond, and in which represen- ɪ of almost all the rock-systems from Cambrian to Eocene ognised.

PITI AREA. (Fig 9)

Silurian.

dying the beds of the Haimanta system in all parts of here are a thick series of red quartzites and grits under- ʼ conglomerates, and passing upwards into shales with of limestone and dolomite. The accompanying table the relations of the Silurian system of Spiti with the ng and underlying formations (see Fig. 9)

Upper Silurian.	Grey coloured siliceous limestones. Coral limestone. Shaly limestones with brachiopods, corals and gastropods.	2000 ft.
Lower Silurian or Ordovician.	Hard grey dolomitic limestones. Dark and grey limestones with *cystidea*, brachiopods and trilobites. Shales and flaggy sandstones and quartzites. Thick mass of pink or red quartzite, gritty unfossiliferous coarse conglomerates.	
Cambrian	Haimanta black shales and slates.	

The lower, arenaceous, beds are unfossiliferous, but the upper shaly and calcareous portion has yielded numerous fossil brachiopods, cystidea, crinoids, corals and trilobites. Of these the most important genera are (Trilobites) *Cheirurus*, *Illaenus*, *Asaphus*, *Calymene* and *Bronteus*, (Brachiopods) *Orthis*, *Strophomena*, *Leptaena*, *Atrypa*, *Pentamerus* (?), (Corals) *Favosites*, *Halysites*, *Cyathophyllum*, *Syringopora* and *Chaetetes*, (Hydrozoa) *Stromatopora*, (Gastropods) *Bellerophon* and *Pleurotomaria*, (Cystoids) *Pyrocystites* and *Craterina*. The above-named genera bear close zoological relations to those obtained from the Silurian of England and Europe, a relationship which extends also to many of their species, a certain number of them being common

vonian. Resting over the Silurian beds is a thick series of white and hard quartzites, which are quite unfossiliferous, whose age therefore, whether Upper Silurian or Devonian, is a matter of uncertainty Since it rests directly over distinctly fossiliferous Silurian beds and underlies fossiliferous strata of undoubted Lower Carboniferous horizon, its age is inferred with a high degree of probability to be Devonian, in part at least. This quartzite is known as the *Muth quartzite* from its occurrence very conspicuously on the pass of that name in Spiti. Dr Hayden is inclined to consider the Muth quartzite as partly Silurian and partly Devonian. "The beds immediately underlying the Muth quartzite contain *Pentamerus oblongus*, and are therefore, of Llandovery age As there is no unconformity here, the overlying beds, at least in part,

FIG. 9.—Section along the Parahio river, Spiti.

1. Haimanta—a. Slates and quartzites. b. Haimanta schists. c. Trilobite beds. d. Haimanta dolomite.

a. Silurian. b. Muth series (Devonian ?). c. Productus shales. d. Trias.

G. Gneiss. T. Trap-dyke.

After Hayden, *Memoirs Geological Survey of India*, xxxvi, pt. 1.

Silurian As the Muth quartzite merely represents an old sandstone, and is therefore probably deposited fairly rapidly, the odds were in favour of the whole of the Muth quartzite being Silurian. It is, however, usually regarded as partly Silurian and partly Devonian "[1] The Muth quartzites, together with an overlying group of hard siliceous limestone, some 300 feet in thickness in the neighbouring locality of Bashahr, may be taken to represent in part at least the Devonian Age in the Himalayas.

Carboniferous.

The Muth quartzite is overlain by a thick series of limestones and quartzites more than 2000 feet in thickness The limestones are hard, dark coloured and splintery They are, however, very prolific in fossils, the fossiliferous bands alternating with white and grey barren quartzites This series is known as the *Lipak series*, from a typical outcrop in the Lipak valley in the eastern part of Spiti. The fossils are characteristic Lower Carboniferous organisms belonging to such brachiopod genera as *Productus* (sp *cora* and *semireticulatus*), *Chonetes*, *Athyris* (sp *roysii*), *Syringothyris* (sp *cuspidata*), *Spirifer*, *Reticularia*,

Lipak series.

[1] Sir H. H. Hayden in a personal note.

iferous trilobite *Phillipsia*, (Cephalopods) *Orthoceras* and *Platyceras*, (Gastropods) *Euomphalus*, *Conularia*, *Pleurotomaria*, (Crustacea) *Estheria*, fish teeth, etc.

Po s.

The Lipak series is succeeded, in the same continuous sequence, by a group of dark coloured shales and quartzites constituting what is known as the *Po series* (See Fig 17) The lower division is for the most part composed of black shales, traversed by intrusive dykes and sheets of dolerite. The intruded rock has induced much contact-metamorphism in the shales, some of which are converted into pyritous slates and even into garnetiferous mica-schists in the immediate neighbourhood of the igneous rock The unaltered shales contain impressions of the leaves of ferns and allied plants, of Lower or Middle Carboniferous affinities, such as *Rhacopteris*, *Sphenopteridium*, *Sphenopteris*, etc The upper division of the Po series is composed of shales and quartzites, the higher part of which contains marine organisms in which the polyzoan genus *Fenestella* preponderates, and gives the name *Fenestella shales* to that sub-division The other fossils are species of *Productus*, *Dielasma*, *Spirigera*, *Reticularia*, *Spirifer*, *Nautilus*, *Orthoceras*, *Protoretepora* (sp *ampla*), etc. From the preponderance of polyzoa and the species of brachiopods characteristic of the Middle Carboniferous, the latter age is ascribed to the Po series

Upper conf as un ormity

The Po series is overlain by Permian strata beginning with a conglomerate. This complete development of the Palaeozoic systems, up to and including the Mid Carboniferous which we have seen in Spiti, is an exceptional circumstance and confined to some parts of Spiti only, for in several other areas of the Central Himalayas, the Permian conglomerate is seen to overlie unconformably formations of far lower horizons, whether Haimanta, Silurian or Muth, all the intervening stages being missing This Permian conglomerate, which will be referred to later in our description of the Permian system, is a most important horizon, a *datum line*, in the geology of India. It covers an unconformity universal in all parts of India where the Permian system is seen In this particular area of Spiti it is not apparent, because

OVERFOLDING OF THE PALAEOZOIC ROCKS, UPPER LIDAR VALLEY CENTRAL HIMALAYAS

S Silurian quartzites, shales and coral limestones. C. Limestones and quartzites of the Lipak and Po series the latter are seen in the form of a syn in which lie the highly crumpled strata of the black Productus shales (P), and the Lower Trias of the *Otoceras* zone (T). Notice the smooth, worn su of the cliff polished by a glacier. *Geological Survey of India, Mem.* vol. xxiii.

rest of the continent, permitting an uninterrupted
entation to proceed in this locality, bridging over the

e break in the continuity of the deposits at the top of
iddle and Upper Carboniferous is utilised by Sir T H
d as the basis for the separation of all the systems
it (collectively forming the Dravidian group), from the
ning systems of later ages which come above it, consti-
the great Aryan group
following table gives a general view of the Palaeozoic
ice in Spiti

Group	System	Series	Description
ip.			Permian to Tertiary
			Basement conglomerate
...ian ip.	Middle Carboniferous.	Po Series, 2000 ft.	Fenestella shales. Shales and quartzite with plants (*Culm*)
	Lower Carboniferous.	Lipak Series, 2000 ft.	Shales and limestones with *Syringothyris* *Spirifera*, etc.
	Devonian.		Muth quartzite and limestone, 800 ft.
	Silurian.		Quartzites, shales and coral limestone, etc., 2000 ft.
	Cambrian.		Haimanta, slates and quartzites with dolomite, 4000-5000 ft.
p.	Pre-Cambrian.		Vaikrita series of schists and phyllites.

KASHMIR.

ratified series, in many respects identical with the above
ice in Spiti, is developed in Kashmir in a "basin" of
ents which lies on a direct north west continuation of the
of the Spiti basin, the only instance within the limits of
of a continuous and conformable well-developed Palaeo-
uccession In these, recent researches by Middlemiss

stratigraphical systems—Cambrian, Ordovician and Silurian, Devonian, Carboniferous and Permian The stratigraphy of Kashmir is treated in Chapter XXVII

3 CHITRAL

In the valley of the Chitral river at the north west frontier, Devonian strata are found containing some of the characteristic brachiopods and corals of the period *Favosites*, *Cyathophyllum*, *Orthis*, *Athyris*, *Atrypa*, *Spirifer* Mr G H Tipper has recently found sections showing conformable sequence from Lower Devonian to the *Fusulina* limestone of Carboniferous age The structure in these mountains is highly complicated, and the Devonian is as a rule thrown against a Tertiary conglomerate by a great fault The Carboniferous occurs in well marked bands and embodies the *Chitral slates* and *Sarikol shales* besides *Fusulina* and some *Bellerophon* beds. Lithologically the Devonian of Chitral is a thick series of limestone overlying a series of older Palaeozoic strata, quartzites, red sandstones and conglomerates, in which are to be recognised the probable equivalents of the Muth quartzite and the Upper Silurian horizons of the better known areas [1]

4 HAZARA

The Lower Palaeozoic of Hazara consist of a coarse basal conglomerate, followed by a series of red or purple sandstones and shales, the whole overlain by a massive limestone some 2000 feet in thickness. The limestone is a compact thin bedded rock of purple colour Its weathering is very peculiar, giving rise to large discoidal blocks Fossil evidence is wanting in these rocks, but from lithological correspondence of the Hazara series with that of Chitral, the two are regarded as being of the same age The name given to the Hazara sequence is the "Infra Trias series," on account of its relation to the immediately overlying, more conspicuous Triassic rocks of the area. (See Figs 20 and 21, pp 156, 157)

5 BURMA (Northern Shan States)

But a much more perfect development of marine Palaeozoic rocks is discovered in the eastern extremity of the extra Peninsula, in the Northern Shan States of Upper Burma, in which the Indian Geological Survey have worked out a succession of faunas, revealing a continuous history of the life and deposits of the Palaeozoic group from Ordovician to Permian. The Northern Shan States of Burma are a solitary instance,

[1] H H Hayden *Rec. G.S I* vol xlv pt. 4, 1915; G H. Tipper *Rec G.S I* vol. lv pp. 38, and vol. lvi. pp. 44-48.

Indian Empire, which pos a complete geological record Palaeozoic era. The extreme of fossiliferous Palaeozoic ystems in the Indian Penin ompels the attention of the student to this distant, h by no means geologically province for study We can ive but the barest outline of ery interesting development fuller details the student l consult the original *Memoir* r La Touche, vol xxxix , 1913

rian. In the Northern Shan , Lower Silurian (Ordovician) are exposed, resting over a outcrop of unfossiliferous rian quartzites and grey s. These in turn overlie still Archaean or Dharwar gneisses Mogok gneiss), with which terbedded the well known lline limestone (the ruby e of Burma), the carrier of a er of precious stones, such as , sapphires and spinels. The vician rocks are variously ed shales and limestones con g the characteristic trilobites, leans and brachiopods of that The characteristic Ordovician of stemmed cystoid, *Aristo-* is noteworthy Also the cys *Caryocrinus* and *Heliocrinus* rachiopods are *Lingula*, *Orthis*, *homena*, *Plectambonites* and

FIG. 10.—Section of Palaeozoic systems of N Shan States (Burma), section across the Nam-tu Valley at Lilu.

1. Chaung Magyi series (Cambrian ?).
2. Naungkangyi beds (Ordovician).
3. Lower Silurian graptolite beds.
4. Namshim sandstone, Upper Silurian.
5. Plateau limestone (Devonian and Permo-Carboniferous).
6. Namyau beds (Jurassic).

La Touche, *Mem.* vol. xxxix, pt. 2.

with some gastropods The trilobites are *Ampyx*, *Asaphus*, *Illaenus*, *Calymene*, *Phacops*, etc

The Ordovician beds are overlain by Silurian strata composed of a series of quartzitic and felspathic sandstones, the lower beds of which contain many trilobites and graptolites The graptolites include characteristic forms like *Diplograptus*, *Climacograptus*, *Monograptus*, *Cyrtograptus*, *Rastrites*, etc The graptolite-bearing beds are succeeded by what are known as the *Namshim series*, containing trilobites of the genera *Illaenus*, *Encrinurus*, *Calymene*, *Phacops*, *Cheirurus*, and numerous brachiopods. The Namshim sandstones are in turn overlain by a newer series of calcareous, fossiliferous, soft yellow and grey limestones and sandstones, constituting the *Zebingyi series* of the Northern Shan States. The fossils of the Zebingyi series include a few species of graptolites of the type-genus *Monograptus*, together with cephalopods and trilobites (*Phacops* and *Dalmanites*), possessing affinities somewhat newer than the Wenlock limestone of England. These fossils indicate an uppermost Silurian age of the enclosing strata. The Zebingyi stage is thus to be regarded as forming the passage-beds between the Silurian and the overlying Devonian

The Silurian fossils obtained from both the Namshim and Zebingyi horizons of the Shan States are

Brachiopods—*Lingula*, *Leptaena*, *Orthothetis*, *Strophomena*, *Orthis*, *Pentamerus*, *Atrypa*, *Spirifer*, *Meristina*.

Lamellibranchs—*Pterinea*, *Modiolopsis*, *Glassia*, *Dualina*, *Conocardium*.

Gastropods—*Tentaculites*

Cephalopods—Many species of *Orthoceras*

Numerous broken stems of crinoids.

Rugose coral—*Lindstroemia*

Worm borings and tubes.

Trilobites—*Illaenus*, *Proetus*, *Encrinurus*, *Calymene*, *Cheirurus*, *Phacops*, *Dalmanites*, and fragments of many other trilobites

The Devonian is represented by a series of crystalline dolomites and limestones of Padaukpin, which have yielded a

nce of Devonian fauna that has been met with
) in the Indian region. The fossils are very numerous
long to all kinds of life of the period—corals,
pods, lamellibranchs, gastropods, cystoids, crinoids,
, crustacea, etc

Devonian fauna of Burma

s—*Calceola* (sp *sandalina*, the characteristic Devonian coral), *Cyathophyllum*, *Cystiphyllum*, *Alveolites*, *Zaphrentes*, *Heliolites*, *Pachypora* etc. — Devonian fauna

zoa—*Fenestrapora*, *Hemitrypa*, *Polypora*.

hiopods—*Orthis*, *Atrypa*, *Pentamerus*, *Chonetes*, *Spirifer*, *Cyrtina*, *Merista*, *Meristella*, etc

llibranchs—*Conocardium*, *Avicula*.

opods—*Loxonema*, *Pleurotomaria*, *Murchisonia*, *Euomphalus*, *Bellerophon*.

alopods—*Anarcestes*

ites—*Phacops*, etc

ids—*Cupressocrinus* *Taxocrinus*, *Hexacrinus*

The Wetwin slates. — imestone and dolomite are followed by an argillaceous f yellow-coloured shales and slates of Upper Devonian own as the *Wetwin slates* also fossiliferous, and con- *Lingula*, *Athyris*, *Chonetes*, *Janeia*, *Nucula* and *Belle*- as the commonest fossils With the Wetwin slates ociated fine crystalline dolomites and limestones with of corals and foraminifera.

Carboniferous and Permo-Carboniferous — Devonian is succeeded, in the same locality and in one ous succession, by a great development of limestones omites belonging to the Lower and Upper Carboniferous rmian systems, which on account of their forming r with the Devonian limestones) the plateau country Northern Shan States, have been collectively known *Plateau limestone*. The limestones, which are exten- rushed and brecciated, vary from pure limestones dolomitic limestones to pure dolomites There is a ferral limestone among them, which, from the pro- nce of *Fusulinae* in it (a rock building *foraminifer* peculiar to this age in many parts of the world), is

known as the *Fusulina limestone.* The fossils of the upper portion of the Plateau limestone very closely correspond in facies with those of the Productus limestone of the Salt-Range (Chapter XI) of Permian age. (See Figs. 10 and 18.)

The faunas throughout the whole series of strata following the Wetwin shales are closely related and are stamped with the same general facies The Lower Carboniferous forms are not separable from the Upper, nor are these from the Permian. For this reason the two groups of Carboniferous and Permian rocks are described under the name of *Anthracolithic* group, a grouping which is applicable to the Permo-Carboniferous rocks of many other parts of India as well

The foregoing facts are summarised in the following table of geological formations of the Northern Shan States, Upper Burma

	Burma	*Other parts*
Rhaetic.	Napeng beds.	
Permo-Carboniferous (anthracolithic) Systems.	Upper plateau limestone *Fusulina* and *Productus* limestones Partly dolomitic and brecciated. In the main unfossiliferous.	Productus limestone of the Salt-Range. Productus shales of Spiti and Zewan beds of Kashmir.
Devonian System.	Crystalline dolomites and limestones, much crushed, with *Calceola sandalina*, *Phacops*, *Pentamerus*, etc (of Padaupkin), forming the plateau country. Wetwin shales with *Chonetes* and a very rich Devonian fauna (Eifelian).	Muth Series and Devonian of Chitral.
Silurian System.	Zebingyi beds, blue and grey flaggy limestones with *Graptolites*, *Tentaculites*, *Orthoceras*. Namshim sandstones, quartzose and felspathic sandstones, soft marls, and limestones with *Orthoceras*, *Trilobites*, etc.	Silurian of Spiti and Kashmir.

Ordovician System.	Nyaungbaw beds—brown limestones with shales containing Upper Ordovician fossils Naungkangyi beds, yellow or purple shales with thick limestones Cystoids, *Orthis*, *Strophomena*, *Trilobites*	Lower Silurian of Kashmir
Cambrian System	Chaung Magyi beds, thick quartzites, slaty shales and greywackes · unfossiliferous	Haimanta of Spiti and Cambrian of the Salt-Range.
Archaean System.	Mogok gneiss, gneiss and interbanded crystalline limestones with intrusive granites	Peninsular gneisses

Physical changes at the end of the Dravidian era

With the Upper Carboniferous, the second great era of the geological time-scale in India ended. Before we pass on to the description of the succeeding rock-groups we have to consider a great revolution in the physical geography of India at this epoch, whereby profound changes were brought about in the relative distribution of land and sea The readjustments that followed these crust-movements brought large areas of India under sedimentation which were hitherto exposed land-masses An immense tract of India, now forming the northern zone of the Himalayas, was covered by the waters of a sea which invaded it from the west, and overspread North India, Tibet and a great part of China This sea, the great Tethys of geologists, was the ancient central or *mediterranean* ocean which encircled almost the whole earth at this period in its history, and divided the continents of the northern hemisphere from the southern hemisphere It retained its hold over the Himalayas for the whole length of the Mesozoic era, and gave rise, in the geosynclinal trough that was forming at its floor, to a system of deposits which recorded a continuous history of the ages between Permian and Eocene. This long cycle of sedimentation constitutes the second and last marine period of the Himalayan area.

During this interval the Peninsula of India underwent a different cycle of geological events. The Upper Carboniferous movements interrupted its long unbroken quiescence since the

Vindhyan Although the circumstance of its being a horst-like segment of the crust gave it immunity from deformations of an orogenic kind, yet it was susceptible to another class of crust-movements, characteristic of such land-masses These manifested themselves in the subsidence of large linear tracts in various parts of the country between more or less vertical fissures of dislocation in the earth (block-type of earth-movements), which eventually resulted in the formation of chains of basin-shaped depressions on the old gneissic land These basins received the drainage of the surrounding country and began to be filled by their fluviatile and lacustrine debris As the sediments accumulated, the loaded basins subsided more and more, and subsidence and sedimentation going on *pari passu*, there resulted thick deposits of fresh-water and subaerial sediments several thousand feet in vertical extent and entombing among them many relics of the terrestrial plants and animals of the time. These records, therefore, have preserved to us the history of the land-surface of the Indian continent, as the zone of marine sediments, accumulated in the geosynclinal of the Northern Himalayas, has of the oceans. Thus a double facies is to be recognised in the two deposition-areas of India in the systems that follow—a marine type in the extra-Peninsula and a fresh-water and subaerial type in the Peninsula

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CHAPTER IX

THE GONDWANA SYSTEM

General.

Rocks of later age than Vindhyan in the Peninsula of India belong to a most characteristic system of land-deposits, which range in age from the Upper Carboniferous, through the greater part of the Mesozoic era, up to the end of the Jurassic. As mentioned in the last chapter, their deposition on the surface of the ancient continent commenced with the new era, the Aryan era This enormous system of continental deposits, in spite of some local unconformities, forms one vast conformable and connected sequence from the bottom to the top. It is distinguished in the geology of India as the Gondwana system, from the ancient Gond kingdoms south of the Narbada, where the formation was first known. Investigations in other parts of the world, viz. in Africa, Madagascar, Australia and even South America, have brought to light an exactly parallel group of continental formations, exhibiting much the same physical as well as organic characters. From the above circumstance, which in itself is conclusive evidence, as well as from the additional proofs that are furnished by important palaeontological discoveries in the Jurassic and Cretaceous systems of India and Africa, it is argued by many eminent geologists that an unbroken land-connection existed between these distant regions across what is now the Indian Ocean in a large southern continent, which extended from western Africa to India, and united within the same borders the Malay Archipelago and Australia. The presence of an immense land expanse in the southern world for a long succession of ages, which permitted of an unrestricted migration of its animal and plant inhabitants within its confines, is indicated by another very telling circumstance It is the effect of such a continent

The ancient Gondwana-land.

on the character and distribution of the living fauna and flora of India and Africa of the present day. Zoologists have traced unmistakable affinities between the living lower vertebrate fauna of India and that of Central Africa and Madagascar, relationships which could never have subsisted if the two regions had always been apart, and each pursued its own independent course of evolution. The northern frontier of this continent was approximately co-extensive with the central chain of the Himalayas and was washed by the waters of the Tethys

The evidence from which the above conclusion regarding the existence of the great south-world continent is drawn, is so weighty and so many-sided that the differences of opinion that exist among geologists appertain only to the details of its geography, the main conclusion being accepted as one of the settled facts in the geology of this part of the world. The subaerial deposits formed by the rivers of this continent during the long series of ages are preserved in a number of isolated basins throughout its area, indicating a general uniformity and kinship of life and conditions on its surface The term Gondwana system has been consequently extended to include all these formations, while the name of *Gondwanaland* is given to this Mesozoic Indo-African continent. The Gondwanaland, called into existence by the great crust-movements at the beginning of this epoch, persisted as a very prominent feature in ancient geography till the commencement of Cainozoic age, when, collaterally with other physical revolutions in India, large segments of it subsided, permanently, under the ocean, to form what are now the Bay of Bengal, the Arabian Sea, etc., thus isolating the Peninsula of India.

The *Gondwana system* is in many respects a unique formation. Its homogeneity from top to bottom, the fidelity with which it has preserved the history of the *land*-surface of a large segment of the earth for such a vast measure of time, the peculiar mode of its deposition in slowly sinking faulted troughs in which the rivers of the Gondwana country poured their detritus, and the preservation of valuable coal-measures lying undisturbed among them, stamp these rocks

with a striking individuality among the geological systems of India

The most important fact regarding the Gondwana system is its *mode of origin* The formation of thousands of feet of river and stream deposits in definite linear tracts cannot be explained on any other supposition than the one already briefly alluded to. It is suggested that the mountain-building and other crustal movements of an earlier date had their reaction now in the subsidence of large blocks of the country to the equilibrium-plane, between vertical or slightly inclined fissures in the crust. These depressions naturally became the gathering-grounds for the detritus of the land, for the drainage system must soon have betaken itself to the new configuration The continually increasing thickness of the sediments that were poured into the basins caused them to sink relatively to the surrounding Archaean or Vindhyan country, from which the sediments were derived, and thus gave rise to a continuation of the same conditions without interruption.

The geotectonic relations of the Gondwana rocks

It is this sinking of the loaded troughs among the Archaean crystalline rocks that has tended to preserve the Gondwana rocks from removal by surface denudation, to which they would certainly have been otherwise subject The more or less vertical faulting did not disturb the original horizontal stratification of the deposits beyond imparting to them a slight tilt now to one direction, now to the other, while it made for their preservation during all the subsequent ages As almost all the coal of India is derived from the coal-seams enclosed in the Gondwana rocks, this circumstance is of great economic importance to India, since to it we owe not only their preservation but their immunity from all crushing or folding which would have destroyed their commercial value by making the extraction of the coal difficult and costly

Their fluviatile origin

The *fluviatile nature* of the Gondwana deposits is proved not only by the large number of the enclosed terrestrial plants, crustaceans, insects, fishes, amphibians, reptiles, etc., and by the total absence of the marine molluscs, corals and crinoids, but also by the character and nature of the very detritus themselves, which give conclusive evidence of the deposition

in broad river-valleys and basins. The rapid alternations of coarse- and fine-grained sandstones, and the numerous local variations met with in the rocks, point to a depositing agency which was liable to constant fluctuations in its velocity and current Such an agency is river water. Further evidence is supplied by the other characters commonly observed in the alluvial deposits of river valleys, such as the frequency of false-bedding, the existence of several local unconformities due to what is known as "contemporaneous erosion" by a current of unusual velocity removing the previously deposited sediment, the intercalations of finely laminated clays among coarsely stratified sandstones, etc.

It is probable that in a few instances the deposits were laid down in lakes and not in river-basins, *e g.* the fine silty shales of the *Talchir stage* at the bottom of the system The distinctive character of the *lacustrine* deposits is that the coarser deposits are confined to the margin of the lake or basin, from which there is a gradation towards the centre where only the finest silts are precipitated Breccias, conglomerates and grits mark the boundary of ancient lakes, while finely laminated sandstones and clays are found in the middle of the basins. This is frequently observed in deposits belonging to the Talchir series

Climatic vicissitudes

The Gondwana system is of interest in bearing the marks of several *changes of climate* in its rocks. The boulder-bed at its base tells us of the cold of a Glacial Age at the commencement of the period, an inference that is corroborated, and at the same time much extended in its application, by the presence of boulder-beds at the same horizon in parts of Rajputana and the Salt-Range This Permian glacial epoch is a well-established fact not only in India, but in other parts of Gondwanaland, *e.g.* in Australia The thick coal-seams in the strata of the succeeding epoch, pointing to a superabundance of vegetation, suggest a much warmer climate. This is followed by another cold cycle in the next series (the *Panchet*), the evidence for which is contained in the presence of undecomposed felspar grains among the clastic sediments. The last-mentioned fact proves the existence of ice among the agents of denudation, by which the

crystalline rocks of the surface were *disintegrated* by frost-action, and not *decomposed* as in normal climates. The thick red Middle Gondwana sandstones succeeding the Panchet epoch denote arid desertic conditions during a somewhat later period, a conclusion warranted by the prevalence in them of so much ferruginous matter coupled with almost the total absence of vegetation

Life of the period

The *organic remains* entombed in the sediments are numerous and of great biological interest, as furnishing the natural history of the large continent, but they do not help us in fixing the homotaxis of the different divisions of the system, in terms of the standard stratigraphical scale, with other parts of the world The palaeontological value of terrestrial and fresh-water fossil organisms is limited, as they do not furnish a continuous and connected history of their evolution, nor is the geographical distribution of their species wide enough, as is the case with the marine molluscs, echinoderms, etc. Plant fossils, however, are abundant, and are of service in enabling the different groups of exposures to be sub-divided and correlated *among themselves* with some degree of minuteness The lower Gondwanas contain numerous pteridosperms, ferns and equisetums, the middle part of the system contains a fairly well-differentiated invertebrate as well as vertebrate fauna of crustacea, insects, fish, amphibia, and reptiles, besides plants, while in the upper division there is again a rich assemblage of fossil plants, now chiefly of the higher vegetable sub-kingdom (spermaphyta), cycads and conifers, with fish and other vertebrate remains.

A succession of distinct *floras* has been worked out from the shale and sandstone beds of the various Gondwana divisions by palaeo-botanists, and distinguished as the *Talchir*, *Damuda*, *Raniganj*, *Rajmahal*, *Jabalpur* flora, etc., each possessing some individual characteristics of its own.

Distribution of the Gondwana rocks.

Outcrops of the Gondwana system are scattered in a number of more or less isolated basins (see Figs. 11 and 12) lying in the older rocks of the Peninsula along certain very definite lines, which follow approximately (though not always) the courses of some of the existing rivers of the Peninsula. Three large tracts in the Peninsula can be marked out as prominent Gond-

wana areas : (1) a large linear tract in Bengal along the valley of the Damodar river, with a considerable area in the Rajmahal hills ; (2) an expansive outcrop in the Central Provinces prolonged to the south-east in a belt approximately following the Mahanadi valley ; (3) a series of more or less connected troughs forming an elongated band along the Godavari river from near Nagpur to the head of its delta Besides these main areas, outliers of the Upper Gondwana rocks occur in Kathiawar, Cutch, Western Rajputana and, the most important of all, along the East Coast The Gondwana system, however, is not confined to the Peninsular part of India only,
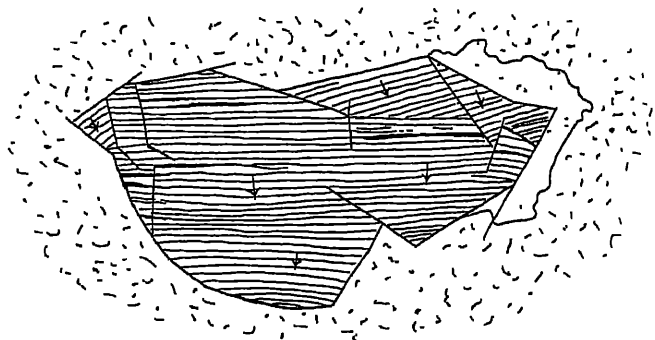
FIG 11 —Sketch map of typical Gondwana outcrop

since we find outliers of the same system to the north of the Peninsula on the other side of the Indo-Gangetic alluvium, at such distant centres as Afghanistan, Kashmir, Sikkim, Bhutan,[1] and the Abor country.[2]

From what has been said regarding their mode of origin and their geotectonic relations with the older rocks into which they have been faulted, the above manner of disposition of the Gondwana outcrops will easily be apparent. It also follows that the boundaries of the outcrops are sharply marked off on all sides, and that there is a zone of somewhat disturbed and fractured rock along the boundary while the main body of the rocks is undisturbed These are actually observed facts, since the Gondwana strata never show

[1] *Rec. G S.I* vol xxxiv pt. 1, 1906

[2] *Rec G S I* vol. xlii. pt 4, 1912.

any folding or plication, the only disturbance being a gentle inclination or dipping, usually to the south but sometimes to the north. The extra-Peninsular occurrences, on the other hand, have been much folded and compressed, along with the other rocks, and as a consequence the sandstones, shales and coal-seams have been metamorphosed into quartzites, slates and carbonaceous (graphitic) schists. These extra-Peninsular occurrences are of interest as indicating the limit of the

FIG 12—Tectonic relations of the Gondwana rocks Vertical scale exaggerated

northern extension of the Gondwana continent and the spread of its peculiar flora and fauna.

Classification.

The system is classified into three principal divisions, the Lower, Middle, and Upper, corresponding in a general way respectively to the Permian, Triassic and Jurassic of Europe. The following table shows the division of the principal sections into series and stages, their distribution in the different Gondwana areas and the names by which they are recognised in these areas:

[Table overleaf.

System.	Series.	Damodar Val.	Rajmahal.	Son and Mahanadi Val.	Satpura.	Godavari.	East Coast	Cutch.	Age.
Up. Gondwana	Umia.	—	—	—	—	—	Tripetty, Pavalur, etc	Umia.	Lower Cretaceous
	Jabalpur	—	—	Jabalpur.	Jabalpur. Bagra.	Chikiala	Raghavapuram, Sripermatur, etc	Jabalpur	Bathonian
	Kota. Rajmahal.	Rajmahal	Rajmahal.	—	—	Kota.	Golapilli and Budavada stages		Lias
Mid. Gondwana	Maleri and Parsora.	—	—	Parsora.	Maleri and Parsora.	Maleri	—		Keuper.
	Kamthi (or Pachmarhi).	Kamthi	Dubrajpur sandstone.	Kamthi	Kamthi or Pachmarhi.	Kamthi or Mangli	—		Muschelkalk.
	Panchet.	Panchet	—	—	Panchet.	Panchet.	—		Bunter
Lr. Gondwana	Damuda.	Raniganj stage.	—	—	Bijori	—	—		Upper Permian
		Ironstone shales stage	—	—	—	—	—		
		Barakar stage	Barakar	Barakar	Barakar or Motur	Barakar	—		Middle Permian.
	Talchir.	Karharbari stage	—	Karharbari	Karharbari	—	—		
		Talchir stage.	Talchir	Talchir.	Talchir	Talchir	—		Permo-Carboniferous

1. LOWER GONDWANA SYSTEM

Talchir series

The lowest beds of the Lower Gondwana are known as the Talchir series, from their first recognition in the Talchir district of Orissa. The series is divided into two stages, of which the lower, the *Talchir stage*, has a wide geographical prevalence, and is present in all the localities where Gondwana rocks are found, from the Rajmahal hills to the Godavari and from Raniganj to Nagpur The group is quite homogeneous and uniform in composition over all these areas, and thus constitutes a valuable stratigraphical horizon The component rocks (300–400 feet thick) are green laminated shales and soft fine sandstones. The sandstones contain *undecomposed* felspar grains, a fact which suggests the prevalence of land-ice and the disruptive action of frost. Glacial conditions are, however, more clearly indicated by a boulder-bed also of very wide prevalence in all the Gondwana areas, containing the characteristically glaciated, striated and facetted blocks of rock brought from afar and embedded in a fine silt-like matrix The presence of fine silty matrix suggests *fluvio-glacial* agency of transport and deposition rather than glacial. The boulders and blocks were transported in floating blocks of ice, and dropped in the Talchir basins, in which the deposition of fine silt was going on. Proofs of similar glacial conditions at this stage (Permian) exist in many other parts of India, viz. the Aravallis, Rajputana, Salt-Range, etc. The Aravallis, it appears, were the chief gathering-grounds for the snow-fields at this time, from which the glaciers radiated out in all directions.

Talchir fossils.

Fossils are few in the Talchir stage, the lower beds being quite unfossiliferous, while only a few remains of terrestrial organisms are contained in the upper sandstones; there are impressions of the fronds of the most typical of the Lower Gondwana ferns *Gangamopteris* and *Glossopteris*; wings of insects, worm-tracks, etc., are the only signs of animal life. The Talchir stage is succeeded by a group of coal-bearing strata known as the *Karharbari stage*, 500–600 feet in thickness, also of wide geographical prevalence. The rocks are grits, conglomerates, felspathic sandstones and a few shales, containing seams of coal. Plant fossils are numerous, the

chief genera being: (Ferns) *Gangamopteris*—eight species, *Glossopteris*—two species and *Sagenopteris*, (Equisetums) *Vertebraria*, *Schizoneura* (like *Calamites*), (Conifers) *Voltzia* and *Albertia*. Besides leaves of these plants there occur some fossil seed-cases and fruits and a large number of stalks or stems of equisetums.

Damuda series

The Talchir series is succeeded by the second division of the Lower Gondwanas, the *Damuda series*, the most important portion of the Gondwana system. Where fully developed, as in the Damuda area of Bengal, the series is divided into three stages, in the descending order:

Raniganj—5000 feet
Ironstone shale—1400 feet
Barakar—2000 feet

Of these the Barakar stage, named from the Barakar branch of the Damodar river, alone is of wide distribution among the Gondwana basins outside Bengal, viz. in the Satpura and the Mahanadi and Godavari valleys, the middle and upper members are missing from most of them, being restricted chiefly to the type-area of the Damodar valley. The *Barakar stage* rests conformably upon the Talchir series, and consists of coarse, soft, usually white, massive sandstones and shales with coal-seams. The Barakars contain a large quantity of coal in thick coal-seams, though the quality of the coal is variable. The percentage of the carbon is sometimes so low that the coal passes into mere carbonaceous shale by the large admixture of clay It is usually composed of alternating bright and dull layers. The coal is often spheroidal, *i.e.* it breaks up into ball-like masses The *Ironstone shales* are a great thickness of carbonaceous shales with concretions (Sphaerosiderites) of impure iron-carbonate and oxides. They have yielded much ore of iron. But this group is of a most inconstant thickness and appears only at a few localities in the Damuda area, being altogether missing from the rest of the Gondwana areas. This is succeeded by the *Raniganj stage* of the Damuda series, named from the important mining town of Bengal. The Raniganj stage is composed of massive, false-bedded, coarse and fine sandstones and red, brown and

BARRIER OF COAL ACROSS KARARIA NALA.

The elephant is standing on the parting between seams 4 and 5. Photo L. L. Fermor. (Geol. Survey of India, Mem. vol. xli.)

black shales, with numerous interbedded coal-seams. The sandstones are felspathic, but the felspar in it is all decomposed, *i.e* kaolinised The coal is abundant and of good quality as a fuel with a percentage of fixed carbon generally above 55.

Igneous rocks of Damuda coal-measures. Many of the coalfields of the Damodar valley, especially those of the eastern part, are invaded by dykes and sills of an ultra-basic rock which has wrought much destruction in the coal-seams by the contact-metamorphism it has induced The invading rock is a mica-peridotite, containing a large quantity of apatite. The peridotite has intruded in the form of dykes and then spread itself out in wide horizontal sheets or sills. Another intrusive rock is a dolerite, whose dykes are thicker, but they are fewer and are attended with less widespread destruction of coal than the former.

Effects of contact-metamorphism. The coal is converted into coke, and its economic utility destroyed The reciprocal effects of contact-metamorphism on the peridotite as well as the coal are very instructive to observe. The peridotite has turned into a pale earthy and friable mass with bronze-coloured scales of mica in it, but without any other trace of its former crystalline structure On the other hand, the coal has coked or even burnt out, becoming light and cindery, and at places it has developed prismatic structure.

The Damuda flora. The Damuda fossils are nearly all plants. The flora is chiefly cryptogamic, associated with only a few spermaphytes. The following are the most common genera ·

(Pteridosperms and Ferns)—*Glossopteris* and *Vertebraria*, sixteen species, *Gangamopteris*, four species, *Sphenopteris*, *Pecopteris*, *Cyclopteris*, *Samaropsis*, *Macrotaeniopteris*, *Oleandridium*, *Dicksonia*, *Actinopteris*, *Sagenopteris*, *Cyathea*, *Ottokaria*, *Barakaria*, *Rhipidiopsis*, *Psygmophyllum*

(Equisetaceae)—*Phyllotheca* and *Schizoneura*.

(Cordaitales)—*Cordaites* (*Noeggerathiopsis*), *Dadoxylon*.

(Coniferae)—*Voltzia*.

(Cycadophyta)—*Taeniopteris*.

Also large numbers of fossil fern-stems (*rhizomes*), seeds and *equisetum*-stems, with *Estheria*, *Labyrinthodonts* and some Fishes.

The Damuda series of other areas In the Satpura area the Damuda series is represented, in its Barakar and Raniganj stages, by about 10,000 feet of sand-

stone and shale, constituting what are known as the Barakar Motur and Bijori stages respectively of this province. The Mohpani and the Pench valley coalfields of the Satpura region belong to the Barakar stage of this series. In the strata of the last-named stage, at Bijori, there occur bones and other remains of a Labyrinthodont (*Gondwanosaurus*). Other fossils include scales and teeth of ganoid fishes, and ferns and equisetums identical with those of Bengal It is quite probable that large expanses of the Lower Gondwana rocks are buried under the basalts of the Satpuras, which must have contained, and possibly still contain, some valuable coal-seams

Another area of the Peninsula where the Damuda series is recognised, though greatly reduced and with a somewhat altered facies, is in the Godavari valley, where a long but narrow band of Lower Gondwana rocks stretches from the old coalfield of Warora to the neighbourhood of Rajahmundri. The Barakar stage of the Damuda series prevails in these outcrops which bear the coal-fields of Warora, Singareni, Bellarpur, etc.

One more outcrop of the Damuda group is seen in the Rewah State, Central India, which at one or two places contains workable coal-seams, *e g* in the Umaria field. The division of the Lower Gondwana, exposed in this field, also is the Barakar

Homotaxis of the Damuda and Talchir series

Few problems in the geology of India have aroused greater controversy than the problem of the lower age limit of the Gondwana system. The Talchir series has been referred, by different authors, to almost every stratigraphic position from Lower Carboniferous to Trias The discovery, however, of a Lower Gondwana horizon in Kashmir, bearing the eminently characteristic ferns *Gangamopteris* and *Glossopteris* overlying the Carboniferous and underlying marine fossiliferous strata of undoubtedly Permian age, has settled the question beyond any doubt. The Upper Carboniferous, or Lower Permian age, attributed to the Talchir horizon by this circumstance is quite in keeping with the internal evidence that is furnished by the Talchir and Damuda floras, as well as by the fish and labyrinthodont remains of Bijori

A further positive evidence leading to the same inference is supplied by the Lower Gondwanas of Victoria and New South

Wales, Australia Here, *Gangamopteris* and other plant-bearing beds of undoubted Gondwana facies, underlain by a glacial deposit, identical with the Talchir boulder-bed, are found interstratified with marine beds which contain a Carboniferous fauna resembling that of the Speckled sandstone group of the Salt-Range

Economics.

The Damuda series contains a great store of mineral wealth in its coal-measures, and forms, economically, one of the most productive horizons in the geology of India. It contains the most valuable and best worked coal-fields of the country. The mining operations required for the extraction of coal from these rocks are comparatively simple and easy because of the immunity of the Gondwana rocks from all folding or plication. Also, coal-mining in India is not so dangerous on account of the absence of the highly explosive gases like marsh-gas ("firedamp") so commonly associated with coal in Europe

[Although coal occurs in India in some later geological formations also—*e.g* in Eocene and Miocene rocks of Assam; in the Eocene of Punjab, Rajputana and Baluchistan, in the Jurassic rocks in Cutch and in the Cretaceous of Assam—the Damuda series is the principal source of Indian coal, contributing nearly 97 per cent of the total yearly coal production. The principal fields are those of Bengal—Raniganj, Jherria, Giridih and Daltonganj The Raniganj coalfield covers an area of 500 square miles, containing many seams of good coal with interbedded ironstones. The thickness of the individual seams of coal is great, often reaching to forty or fifty feet, while a thickness of eighty or more feet is not rare. The annual output of coal from the Raniganj mines is more than five million tons. The Jherria field has at present the largest output, 10,000,000 tons *per annum.* The coal of the Jherria fields belongs in geological age to the Barakar stage It has less moisture and greater proportion of fixed carbon than that of the Raniganj stage. The coal-fields of Bokaro, to the west of Jherria, contain thick seams of valuable coal, and are in course of development Their total resources are estimated at 1500 million tons. Besides the foregoing there are smaller fields in the Damodar valley. The coal-fields of the other Gondwana areas are not so productive, the more important of them being the Umaria field of Central India in Rewah, the Pench valley and Mohpani and Bellarpur fields of the Central Provinces, and the Singareni of Haiderabad But their aggregate yield is less than one million tons per annum.]

Besides coal, iron is the chief product mined from the Damuda rocks, while beds of fire-clay, china-clay, or kaolin, terra-cotta clays for the manufacture of fire-bricks, earthenware and porcelain, etc., occur in considerable quantities in Bengal and the Central Provinces The Barakar sandstones and grits furnish excellent material for millstones.

During recent years Dr. G. de P. Cotter, in an attempt to subdivide the Gondwana system on palaeobotanical basis, has found it more appropriate, on the evidence of an interesting suite of plant fossils obtained from the Parsora beds of South Rewa, to include among the Lower Gondwanas the thick zone of strata which overlies the Damuda series and underlies the Rajmahal, embodying in fact the group that has been here treated as Middle Gondwana. Dr. Cotter names these strata in question *Panchet series* (divided into three stages—*Panchet, Maleri and Parsora*) and groups them along with the Talchir and Damuda series in the Lower Gondwana The Parsora fossils are *Danaeopsis hughesi, Thinnfeldia, Cladophlebis, Cordaites hislopi,* and *Glossopteris indica,* which though not conclusive in their evidence, do indicate a greater affinity with the Lower than with the Upper Gondwana. The classification that is here adopted was originally based on the views of Fiestmantel and Vredenburg, but chiefly on lithological considerations and the physical conditions of the period embracing the Middle Gondwanas, which were strikingly different from those prevailing in the Damuda and Rajmahal eras.

CHAPTER X.

THE GONDWANA SYSTEM (*Continued*)

2. MIDDLE GONDWANAS

BETWEEN the upper beds of the Damuda series and the next overlying group of strata, distinguished as the Panchet, Kamthi and Maleri series, there is an unconformable junction; in addition there exists a marked discordance in the lithological composition and in the fossil contents of these groups. For these reasons the three series overlying the coal-bearing Damudas have been separately grouped together under the name of Middle Gondwanas by Mr. E. W. Vredenburg[1] Usually it is the practice to regard a portion of the latter group as forming the upper portion of the Lower Gondwanas, and the remaining part as belonging to the bottom part of the Upper Gondwanas, but, in view of the above dissimilarities, as well as of the very pronounced lithological resemblance of what are so distinguished as the Middle Gondwanas with the Triassic system of Europe, it is convenient, for the purpose of the student at any rate, to regard the middle division as a separate section of the Gondwana system.

Rocks. The rocks which constitute the Middle Gondwanas are a great thickness of massive red and yellow, coarse sandstones, conglomerates, grits and shales, altogether devoid of coal-seams or of carbonaceous matter in any shape Vegetation, which flourished in such profusion in the Lower Gondwanas, became scanty, or entirely disappeared, for the basins in which coarse red sandstones were deposited must have furnished very inhospitable environments for any luxuriant growth of plant life. The type area for the development of this formation

[1] *Summary of the Geology of India*, Calcutta, 1910.

is not Bengal but the Mahadeva hills in the Satpura Range, where they form a continuous line of immense escarpments which are wholly composed of unfossiliferous red sandstone. (See Fig. 13, sketch map of the Mid-Gondwanas of the Satpura area, and Fig. 14, generalised section across it) On this account the Middle Gondwanas have also received the name of the *Mahadeva series* The railway from Bombay to Jabalpur, just east of Asirgarh, gives a fine view of these massive steep scarps looking northwards The other localities where
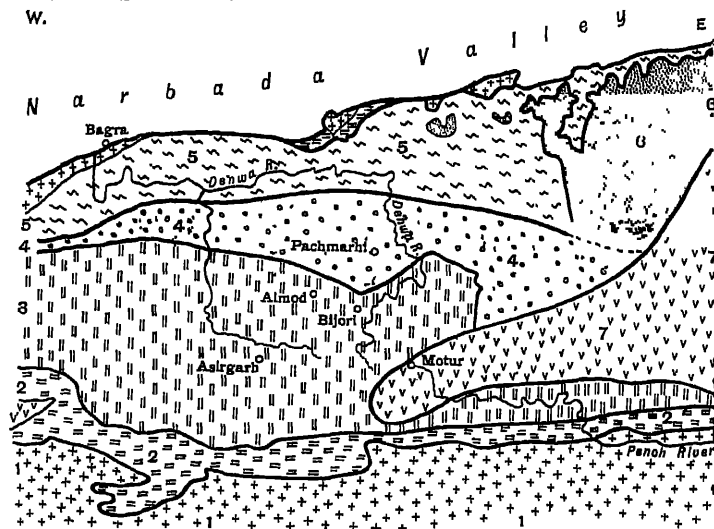
FIG. 13 —Sketch map of the Gondwana rocks of the Satpura area

1 Archaean
2 Talchir
3 Damuda
4 Pachmarhi (Kamthi)
5 Denwa (Maleri) and Bagra.
6. Jabalpur
7 Deccan Trap

Medlicott, *Mem. G S India*, vol x pl 1, 1873.

the strata are well developed, though not in equal proportions, are the Damuda valley of Bengal and the chain of basins of the Godavari area The whole group of the Middle Gondwanas is sub-divided into three series, of which the middle alone is of wide extension, the other two being confined to one or two local developments :

Maleri (and Parsora series)—variable thickness.
Kamthi (or Pachmarhi series)—3000 feet to 8000 feet.
Panchet series—1500 feet.

Panchet series. The *Panchet series* rests directly over the Raniganj stage of the Damuda series. They consist of white and greenish coarse, felspathic sandstones with conspicuous false-bedding interbedded with red clays or shales. The felspar in the sandstone occurs in undecomposed grains. Many of the sandstones here are micaceous The Panchet beds rest with a slight unconformity on the denuded surface of Raniganj stage and at some places on the Barakars through overlapping of the former. The group is of importance, as containing many well-preserved remains of vertebrate animals, affording us a glimpse of the higher land-life that inhabited the Gondwana continent. These vertebrate fossils consist of the teeth, scales, scutes, jaws, vertebrae and other bones of terrestrial and fresh-water fishes, amphibians and reptiles Three or four genera of labyrinthodonts (belonging to the extinct order *Stegocephala* of the amphibians) have been discovered, besides several genera of primitive and less differentiated reptiles.

Panchet fossils ·

> (Amphibia) *Gonioglyptus*, *Glyptognathus*, and *Pachygonia*; (Reptiles) *Dicynodon* and *Epicampodon* The fresh-water crustacean *Estheria* is very abundant at places.

Kamthi series. The *Kamthi Series* is the most conspicuous and the best-developed member of the Middle Gondwana in the Central Provinces. It originally took its name from a military station near Nagpur, where it consists of

FIG 14 —Generalised section through the Gondwana basin of the Satpura region
1 Archaean. 2 Talchir. 3 Damuda {Bijori, Motur} 4 Pachmarhi (Kamthi) 5. Maleri (Denwa) and Bagra 6 Jabalpur 7 Deccan Trap
(After Medlicott.)

some 4000 feet of variously coloured massive sandstones, with ferruginous and micaceous clays, grits and conglomerates In the Damuda area in Bengal the Kamthi horizon is also recognised. There the series is of moderate development aggregating as much as 1000 feet, and at many places within the Damuda area it rests directly over the Barakar stage without the intervening stages, belonging to the Damuda and Panchet series. This circumstance has led to the Kamthi strata being misinterpreted as part of the coal-bearing Damuda series, especially when the unconformable junction between the two was inconspicuous or concealed.

The most typical development of the Kamthi series is, however, in the Mahadeva and Pachmarhi hills of the Satpura range, where it is exposed in the gigantic escarpments of these hills Here the series is composed essentially of thick-bedded massive sandstones, locally called Pachmarhi sandstones, variously coloured by ferruginous matter; in addition to sandstone there are a few shale beds which also contain a great deal of ferruginous matter, with sometimes such a concentration of the iron oxides in them locally that the deposits are fit to be worked as ores of the metal The sandstones as well as shales are frequently micaceous. The Kamthi shales contain beautifully preserved leaves of ferns and equisetaceous plants along their planes of lamination. Some animal remains are also obtained, including parts of the skeletons of vertebrates similar to those occurring in the Panchet beds. The most important is an amphibian—*Brachyops.* This labyrinthodont was obtained from a quarry of fine red sandstone which lies at the bottom of the series forming a group known as the *Mangli beds* near the village of Mangli. The flora of the Kamthi series consists of ferns and equisetums, several species of *Vertebraria* and *Phyllotheca* being found with the ferns *Glossopteris*, *Gangamopteris*, with *Pecopteris*, *Angiopteridium*, and *Danaeopsis*; the species *D. Hughesi* being very characteristic of the Kamthis. This flora resembles that of the Damuda series in many of its forms, being for the most part the survivors of the latter flora.

Maleri series.

The *Maleri* (or *Denwa*) *series* comes generally conformably on the top of the last. Its development is restricted to the

Satpura and Godavari regions. Lithologically it is composed of a thick series of clays with a few beds of sandstones. Plant fossils are, curiously enough, quite absent from the clay beds, though they are admirably fitted to contain and preserve any vegetation entombed. Animal remains, on the other hand, are abundant. The shales are full of coprolitic remains of reptiles. Teeth of the Dipnoid fish *Ceratodus*, similar to the mud-fish living in the fresh waters of the present day, and bones of labyrinthodonts like *Mastodonsaurus*, *Gondwanosaurus*, *Capitosaurus* and *Metopias* are met with in the Maleri rocks of Satpura. Three reptiles, identical in their zoological relations with those of the Trias of Europe, are also found in the rocks, they are referred to the genera *Hyperadapedon* (order *Rhynchocephala*), *Belodon*, and *Parasuchus* (order *Crocodilia*) The Maleri group is well represented in the Godavari valley also, and it is from the discovery of reptilian remains at Maleri, a village near Sironcha, that the group has taken its name. It here rests with an unconformity on the underlying Kamthi beds, and consists of bright red clays with pale-coloured sandstone beds. The shales are full of coprolite remains of reptiles Other fossils from the same locality include *Ceratodus* and the reptiles of the genus *Hyperadapedon* and *Parasuchus* The Maleri group is succeeded by another fossiliferous group, the *Kota stage*. Its affinities, however, are with the Upper Gondwanas, and will be described in connection with them. The combined groups are sometimes designated as the *Kota-Maleri stage*.

Triassic age of the Middle Gondwanas.

From the foregoing account of the Middle Gondwanas it must have been clear that they closely agree in their lithology with the continental facies of the Triassic (the New Red Sandstone) system of Europe. At the same time the terrestrial forms of life, like the crustaceans, fish, amphibia and reptiles that are preserved in them, indicate that they are as akin biologically as they are physically to the English Trias. There are, however, no indications in these rocks of that wonderful differentiation of reptilian life which began in the Triassic epoch in Europe and America, and gave rise, in the succeeding Jurassic period, to the numerous highly specialised races of reptiles that adapted themselves

to life in the sea and in the air as much as on the land, and performed in that geological age much the same office in the economy of nature as is now performed by the class of Mammals.

3. THE UPPER GONDWANA SYSTEM

Distribution

Upper Gondwana rocks are developed in a number of distant places in the Peninsula, from the Rajmahal hills in Bengal to the neighbourhood of Madras The outcrops of the Upper Gondwanas, as developed in their several areas, viz Rajmahal hills, Damuda valley, the Satpura hills, the Mahanadi and Godavari valleys, Cutch and along the Eastern coast, are designated by different names, because of the difficulty of precisely correlating these isolated outcrops with each other. It is probable that future work will reveal their mutual relations with one another more clearly, and will render possible their grouping under one common name At Cutch and along the Coromandel coast, beds belonging to the upper horizon of the Gondwanas are found interstratified with marine fossiliferous sediments, a circumstance of great help to geologists in fixing the time-limit of the Upper Gondwanas, and determining the homotaxis of the system in the stratigraphical scale.

Lithology.

Lithologically the Upper Gondwana group is constituted of the usual massive sandstones and shales closely resembling those of the Middle Gondwanas, but is distinguished from the latter by the presence of some coal-seams and layers of lignitised vegetable matter, and a considerable development of limestones in some of its outcrops, while one outcrop of the Upper Gondwanas, viz. that at the Rajmahal hills, is quite distinct from the rest by reason of its being constituted principally of volcanic rocks. This volcanic formation is composed of horizontally bedded basalts contemporaneously erupted, which attain a great thickness.

Rajmahal series.

Upper Gondwana rocks are found in Bengal at two localities, the Damuda valley and the Rajmahal hills, the latter being the more typical locality. The rocks of the *Rajmahal series* in the Rajmahal hills rest unconformably on the underlying

Kamthi sandstones, the upper portion of which is locally known under the name of the *Dubrajpur sandstone*, the Rajmahal series consists of 2000 feet of bedded basalts or dolerites, with interstratified sedimentary beds (*inter-trappean beds*) of siliceous and carbonaceous clays and sandstones Almost the whole mass of the Rajmahal hills is made up of the volcanic flows, together with these inter-trappean sedimentary beds The shales have turned porcellanoid and lydite-like on account of the contact-effects of the basalts The basalt is a dark-coloured, porphyritic and amygdaloidal rock, commonly fine-grained in texture. When somewhat more coarsely crystalline it resembles a dolerite. The amygdales are filled with beautiful chalcedonic varieties of silica, calcite, zeolites or other secondary minerals. A radiating columnar structure due to "prismatic" jointing is produced in the fine-grained traps at many places. It is probable that these superficial basalt-flows of the Rajmahal series are connected internally with the dykes and sills that have so copiously permeated the Raniganj and other coal-fields of the Damuda region, as their underground roots. The latter are hence the hypabyssal representatives of the subaerial Rajmahal eruptions The silicified shales of the Rajmahal beds have yielded a very rich collection of fossil flora, consisting of perfectly preserved leaves of the following genera of plants: (Ferns) *Danaeopsis, Thinnfeldia, Alethopteris, Gleichenites, Cladophlebis*; (Equisetum) only one genus *Equisetites*; (Cycadophyta) *Ptilophyllum, Zamites, Otozamites* (three species), *Dictyozamites, Cycadites, Pterophyllum* (nine species), *Williamsonia, Nilssonia* and *Bucklandia*; (Conifers) *Cunninghamites, Echinostrobus, Chirolepis* and *Palissya*. The absence of many species of ferns and the almost total disappearance of the equisetums, with the great preponderance, numerical as well as generic, of cycads, are very striking features of the Rajmahal flora when contrasted with the Damuda flora, and denote a great advance in vegetable life since the Raniganj age. The Rajmahal, with the other collateral series of Upper Gondwana in other parts of the Peninsula, can fitly be called an age of gymnosperms, from the predominance of the cycads. The supremacy of the pteridophytes had declined, though many forms yet persisted

Rajmahal flora.

and held an important place in the vegetation of the Gondwana areas.

Satpura and Central Provinces

Upper Gondwana rocks, of an altogether different facies of composition from that at Rajmahal, are developed on a very large scale in these areas. The base of the series rests unconformably on the underlying Maleri beds, and successively covers, by overlapping, all the older members of the Middle and Lower Gondwanas exposed in the neighbourhood The rocks include two stages the lower *Bagra* and the upper *Jabalpur stage.* The Bagra stage consists of limestones, clays and sandstones, with conglomerates. It is succeeded by the next stage, named after the town of Jabalpur The rock components of the Jabalpur stage are chiefly soft massive sandstones and white or yellow shales, with some lignite and coal seams, and in addition a few limestone bands. The Jabalpur stage is of palaeontological interest because of its having yielded a rich Jurassic flora distinct from that of the preceding series and of somewhat newer age, viz Lower Oolite It differs from the Rajmahal flora mainly in its containing a greater proportion of cycads and conifers, viz. *Podozamites, Otozamites, Ptilophyllum,* etc., and *Palissya, Araucarites, Echinostrobus, Taxites, Ginkgoites,* etc.

Jabalpur stage.

Godavari Basin.

A narrow triangular patch of Upper Gondwana rocks occurs in the Godavari valley south of Chanda. The rocks are of the same type as those of the Satpuras, with the exception of the top member, which is highly ferruginous in its constitution. At places the oxides of iron are present to such an extent as to be of economic value. Here also two stages are recognised : the lower *Kota stage*, some 2000 feet in thickness, and the upper *Chikiala stage*, about 500 feet, composed of highly ferruginous sandstones and conglomerates. The Kota stage is fossiliferous, both plant and animal remains being present in its rocks in large numbers. The Kota stage, which overlies the Maleri stage described above, consists of

Kota stage.

loosely consolidated sandstone, with a few shale beds and with some limestones From the last beds numerous fossils of reptiles, fish, and crustacea have been obtained, *e g* several species of *Lepidotus*, *Tetragonolepis*, *Dapedius*, *Ceratodus*; and the reptiles *Hyperadapedon*, *Pachygonia*, *Belodon*, *Parasuchus*, *Massospondylus*, etc The plants include the conifers *Palissya*, *Araucarites* and *Chierolepis*, and numerous species of cycads belonging to *Cycadites*, *Ptilophyllum*, *Taxites*, etc., resembling the Jabalpur forms. The Chikiala stage is unfossiliferous, being often strongly ferruginous (haematitic) and conglomeratic.

Gondwanas of the East Coast.

The Coastal system. Along the Coromandel coast, between Vizagapatam and Tanjor, there occur a few small isolated outcrops of the Upper Gondwanas along a narrow strip of country between the gneissic country and the coast-line. These patches are composed, for the most part, of marine deposits formed not very far from the coast, during temporary transgressions of the sea, containing a mingling of marine, littoral organisms with a few relics of the plants and animals that lived near the shore. Near the Peninsular mainland there are consequently to be seen in these outcrops both fossil plants of Gondwana facies and the marine or estuarine molluscs. In geological horizon the different outliers correspond to all stages from the Rajmahal to the uppermost stage (Umia).

Rajahmundri outcrop.

The principal of these outcrops is the one near the town of Rajahmundri on the Godavari delta. It includes three divisions:

Tripetty sandstone—150 feet.
Raghavapuram shales—150 feet.
Golapili sandstones—300 feet.

This succession of beds rests unconformably over strata of the Kamthi series. Lithologically they are composed of littoral sandstones, gravel and conglomerate rock, with a few shale-beds. The latter contain some marine lamellibranchs (*e.g.* species of *Trigonia*) and a few species of ammon-

ites. Intercalated with these are some beds containing impressions of the leaves of cycads and conifers.

Ongole outcrop

Another outcrop of the same series of beds is found near the town of Ongole, on the south of the Kistna. It also consists of three sub-divisions, all named after the localities:

Pavaloor beds—red sandstone
Vemavaram beds—shales
Budavada beds—yellow sandstone.

The Vemavaram shales contain a very rich assemblage of Gondwana plants, related in their botanical affinities to the Jabalpur plants

Madras outcrop

A third group of small exposures of the same rocks occurs near Madras, in which two stages are recognised. The lower beds form a group which is known as the *Sripermatur beds*, consisting of whitish shales with sandy micaceous beds containing a few cephalopod and lamellibranch shells in an imperfect state of preservation; the plant fossils obtained from beds associated in the same horizon correspond in facies to the Jabalpur flora The Sripermatur beds are overlain by a series of coarser deposits, consisting of coarse conglomerates interbedded with sandstones and grits, which contain but few organic remains. This upper division is known as the *Sattavadu beds*.

One more exposure of the same nature, occurring far to the north on the Mahanadi delta, is seen at Cuttack. It is composed of grits, sandstones and conglomerates with white and red clays. The sandstone strata of this group are distinguished as the *Athgarh sandstones*. They possess excellent qualities as building stones, and have furnished large quantities of building material to numerous old edifices and temples, of which the temple of Jagan Nath Puri is the most famous.

Umia Series.

Upper Gondwanas of Cutch.

The highest beds of the Upper Gondwanas are found in Cutch, at a village named Umia. They rest on the top of a thick series of marine Jurassic beds (to be described with the Jurassic rocks of [illegible] chapter).

The *Umia series*, as the whole formation is called, is a very thick series of marine conglomerates, sandstones and shales, in all about 3000 feet in thickness. The special interest of this group lies in the fact that with the topmost beds of this series, containing the relics of various cephalopods and lamellibranchs, there occur interstratified a number of beds containing plants of Upper Gondwana facies, pointing unmistakably to the prevalence of Gondwana conditions at the period of deposition of this series of strata. The marine fossils are of uppermost Jurassic to lower Cretaceous affinities, and hence serve to define the upward stratigraphic limit of the great Gondwana system of India within very precise bounds. The Umia plant-remains are thought to be the newest fossil flora of the Gondwana system. The following is the list of the important forms:

(Ferns) *Oleandridium, Pachypteris, Pecopteris, Cladophlebis*; (Cycadophyta) *Ptilophyllum, Taeniopteris, Otozamites, Cycadites, Cycadolepis, Williamsonia*; (Conifers) *Palissya, Pachyphyllum, Echinostrobus* and *Araucarites*.

Some of the species of these genera are allied to the Jabalpur species, others are distinctly newer, more highly evolved types.

The Umia beds have also yielded the remains of a reptile, a species belonging to the famous long-necked *Plesiosaurus* of the European Jurassic. It is named *P. Indica.*

In Northern Kathiawar there is a large patch of Jurassic rocks occupying the country near Dhrangadhra and Wadhwan which corresponds to the Umia group of Cutch in geological horizon. It has yielded conifers and cycads resembling the Umia plants.

Economics. The Upper Gondwana rocks include several coal-seams, but they are not worked. Some of its fine-grained sandstones, *e.g.* those of Cuttack, are much used for building purposes, while the clays obtained from some localities are utilised for a variety of ceramic manufactures. The soil yielded by the weathering of the Upper Gondwanas, as of nearly all Gondwana rocks, is a sandy shallow soil of poor quality for agricultural uses. Hence outcrops of the Gond-

wana rocks are marked generally by barren landscapes or else they are covered with a thin jungle. The few limestone beds are of value for lime-burning, while the richly haematitic or limonitic shales of some places are quarried for smelting purposes. The coarser grits and sandstones are cut for millstones.

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CHAPTER XI

UPPER CARBONIFEROUS AND PERMIAN SYSTEMS

The commencement of the Aryan era

In the last two chapters we have followed the geological history of the Peninsula up to the end of the Jurassic period. Now let us turn back to the other provinces of the Indian region where a different order of geological events was in progress during this long cycle of ages.

As referred to before, the era following the Middle Carboniferous was an era of great earth-movements in the extra-Peninsular parts of India, by which sedimentation was interrupted in the various areas of deposition, the distribution of land and sea was readjusted, and numerous other changes of physical geography profoundly altered the face of the continent. As a consequence of these physical revolutions there is, almost everywhere in India, a very marked break in the continuity of deposits, represented by an unconformity at the base of the Permian system of strata. Before sedimentation was resumed, these earth-movements and crustal re-adjustments had resulted in the easterly extension over the whole of Northern India, Tibet and China of the great Mediterranean sea of Europe, which in fact at this epoch girdled almost the whole earth as a true *mediterranean* sea, separating the great Gondwana continent of the south from the Eurasian continent of the northern hemisphere. The southern shores of this great sea, which has played such an important part in the Mesozoic geology of the whole Indian region—the Tethys—coincided with what is now the central chain of snow-peaks of the Himalayas, beyond which it never transgressed; but, to the east and west of the Himalayan chain, bays of the sea spread over areas of Upper Burma and Baluchistan, a great distance to the south of this line,

while an arm of the same sea extended towards the Salt-Range and occupied that region, with but slight interruptions, almost up to the end of the Eocene period It is in the zone of deep-water deposits that began to be formed on the floor of this Central sea at this time that the materials for the geological history of those regions are preserved for the long succession of ages, from the beginning of the Permian to the middle of the Eocene period, constituting the great Aryan era of Indian geology.

The nature of geosynclines.

[Portions of the sea-floor subsiding in the form of long narrow troughs concurrently with the deposition of sediments, and thus permitting an immense thickness of deep-water deposits to be laid down over them without any intermission, are called *Geosynclines* It is the belief of some geologists that the slow continual submergence of the ocean bottom, which renders possible the deposition of enormously thick sediments in the geosynclinal tracts, arises, in the first instance, from a disturbance of the *isostatic* conditions of that part of the crust, further accentuated and enhanced by the constantly increasing load of sediments over localised tracts. The adjacent areas, on the other hand, which yield these sediments, have a tendency to rise above their former level, by reason of the constant unloading of their surface due to the continued exposure to the denuding agencies. They thus remain the feeding-grounds for the sedimentation-basins This state of things will continue till gravity has restored the isostatic equilibrium of the region by a sufficient amount of deposition in one area and denudation in the other. At the end of this cycle of processes, after prolonged intervals of time, a reverse kind of movement will follow in this flexible and comparatively weak zone of the crust, compressing and elevating these vast piles of sediments into a mountain-chain, on the site of the former geosyncline.

Geosynclines are thus long narrow portions of the earth's outer shell which are relatively the weaker parts of the earth's circumference, and are liable to periodic alternate movements of depression and elevation. It is such areas of the earth which give rise to the mountain-chains when they are, by any reason, subjected to great lateral or tangential compression. Such a compression occurs, for instance, when two large adjacent blocks of the earth's crust—horsts—are sinking towards the earth's centre during the secular contraction of our planet, consequent upon its continual loss of internal heat. The bearing of these conceptions on the elevation of the Himalayas, subsequent to the great cycle of Permo-Eocene deposits on the northern border of India, is plausible enough. The Himalayan zone is, according to this view, a geosynclinal tract squeezed between the two large continental masses of Eurasia and Gondwanaland. This subject is, how-

ever, one of the unsettled problems of modern geology, and one which is yet *sub judice*, and is, therefore, quite beyond the scope of this book]

The records of the Himalayan area which we have now to study reveal an altogether different geological history from what we have known of the Gondwana sequence It is essentially a history of the oceanic area of the earth and of the evolution of the marine forms of life, as the latter is a history of the continental area of the earth and of the land plants and animals that inhabited it This difference emphasises the distinction between the stable mass of the Peninsula and the flexible, relatively much weaker extra-Peninsular area subject to the periodic movements of the crust. In contrast to the Peninsular horst, the latter is called the geosynclinal area

The Upper Carboniferous and Permian. The Upper Carboniferous and Permian systems are found perfectly developed in two localities of extra-Peninsular India, one in the western part of the Salt-Range and the other in the northern ranges of the Himalayas.

FIG 15 —Section from Swas to the N E across the hills Scale horizontal 1 inch=1 mile N.E. and S.W. Wynne, *Memoir, Geological Survey of India*, vol. xiv

I. UPPER CARBONIFEROUS AND PERMIAN OF THE SALT-RANGE

After the Salt-pseudomorph shale of the Cambrian age, the next series of deposits that was laid down in the Salt-Range area belongs to this system. Since the Cambrian the

Salt-Range, in common with the Peninsula, remained a bare land area exposed to denudational agencies, but, unlike the Peninsula, it was brought again within the area of sedimentation by the late Carboniferous movements. From this period to the close of the Eocene, a branch of the great central sea to the north spread over this region and laid down the deposits of the succeeding geological periods, with a few slight interruptions. These deposits are confined to the western part of the Range, beyond longitude 72° E, where they are exposed in a series of more or less parallel and continuous

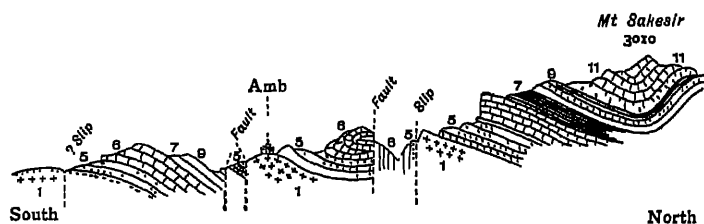



FIG 16 —Section across Mt Sakesir to show relations of the Carboniferous and Permian rocks

Wynne, "Salt-Range," *Geological Survey of India*, vol xiv

outcrops running along the strike of the range In the eastern part of these mountains, Permo-Carboniferous rocks are not met with at all, the Cambrian group being there abruptly terminated by a fault of great throw, which has thrust the Nummulitic limestone of Eocene age in contact with the Cambrian.

The Permo-Carboniferous rocks of the western Salt-Range are a thick series of highly fossiliferous strata. A two-fold division is discernible in them: a lower one composed of sandstones, and an upper one mainly of limestones, characterised by an abundance of the brachiopods *Productus*, and hence known as the *Productus limestone.* The Productus limestone constitutes one of the best developed geological formations of India, and, on account of its perfect development, is a type of reference for the Permian system of the other parts of the world.

The table below shows the chief elements of the Permo-Carboniferous system of the Salt-Range:

Series	Division	Stage	Lithology	Age
Productus limestone (500 ft. maximum thickness).	*Upper* 100 ft	*Chidru* Stage	Marls and sandstones	Upper Permian.
		Kundghat „	Sandstones with *Bellerophons*.	
		Jabi „	Sandy limestones.	
	Middle 300 ft	*Kalabagh* „	Crinoidal limestones with marls and dolomites.	Middle Permian.
		Virgal „	Cherty limestones	
	Lower 100 ft.	*Katta* „	Arenaceous limestones and calcareous sandstones	
		Amb „	Calcareous sandstones.	Permo-Carboniferous.
Speckled sandstones (500 ft. maximum thickness)	*Speckled sandstones,* 300 ft.		Clays, grey and blue Mottled sandstones, lower part fossiliferous.	Upper Carboniferous.
	Boulder bed, 100-200 ft.		Glaciated boulders in a fine matrix.	

Boulder beds.

The basement bed of the series is a boulder-conglomerate of undoubted glacial origin, which from its wide geographical occurrence in strata of the same horizon, in such widely separated parts of India as the Salt-Range, Rajputana, Orissa and various other localities wherever the Lower Gondwana rocks have been found, has been made the basis of an inference of a Glacial Age at the commencement of the Permian period throughout India The evidence for this inference of Permian Ice Age in India lies in the existence of the characteristic marks of glacial action in all these areas, viz. beds of compacted "boulder-clay" or glacial drift, resting upon an under surface which is often sharply defined by being planed and striated by the glaciers. The most striking character of a boulder-clay is its heterogeneity, both in its component materials, which have been transported from distant sources, and in the absence of any assortment and stratification of these materials. Many of the boulders in the boulder-bed of the Salt-Range are striated and polished blocks of the Malani rhyolites of Vindhyan age—an important formation of Rajputana. These are intermixed with smaller pebbles from various other crystalline rocks of the same area, and embedded in a fine dense matrix of clay. Besides

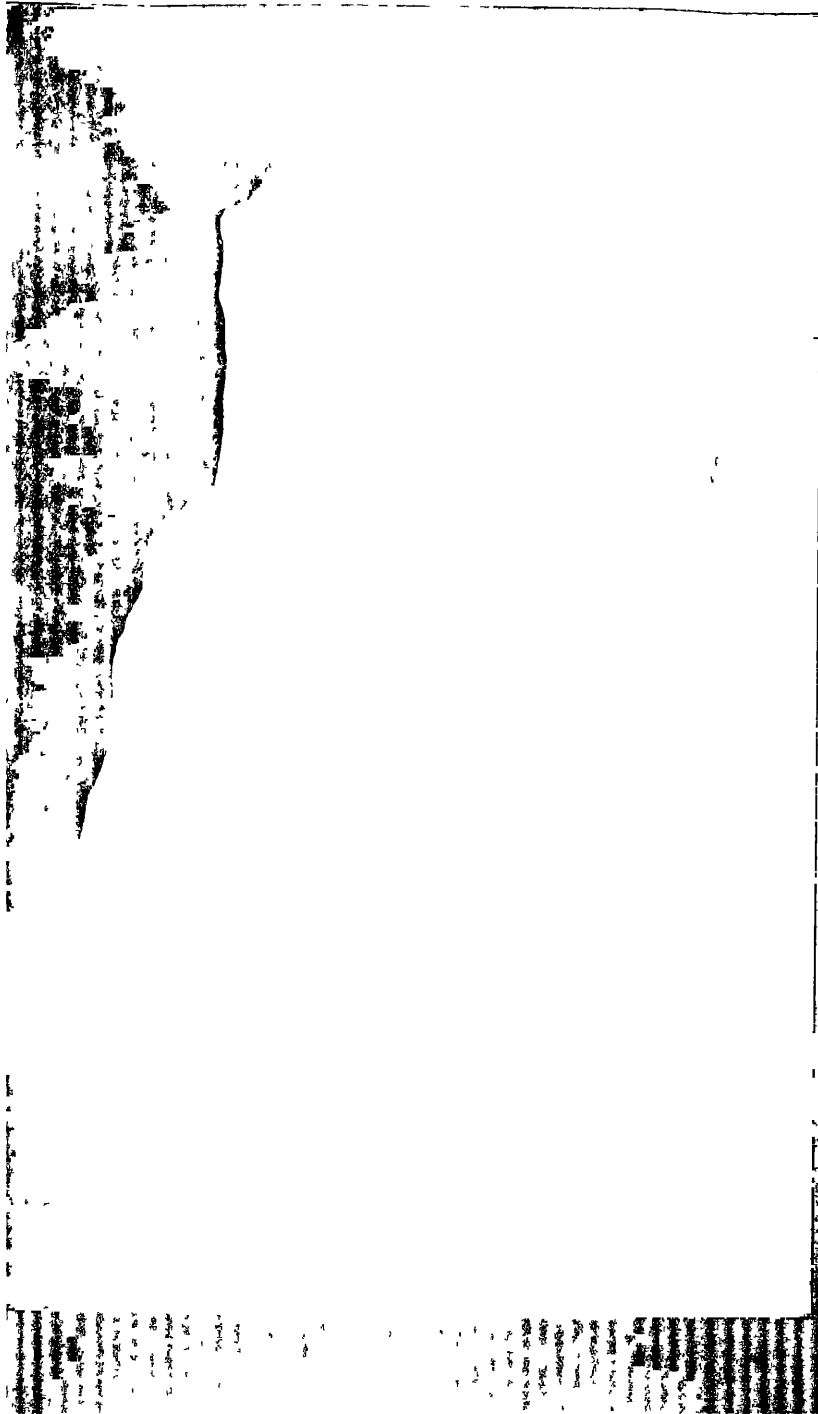
striations and polishing, a certain percentage of the pebbles and boulders shows distinct "facetting." The Aravalli region must have been the home of enormous snow-fields nourishing powerful glaciers at this time, as the size of the boulders as well as the distances to which they have been transported from their source clearly testify to the magnitude of the glaciers radiating from it

Boulder-beds similar to that of the Salt-Range, and also like them composed of ice-borne boulders of Malani rhyolites and other crystalline rocks, are found in Rajputana in Marwar (Jodhpur State) and are known as the Bap and Pokaran beds, from places of that name. At the latter place there occur typical *roches moutonnées*

The Speckled sandstones.

The boulder-bed is overlain by a group of marine sandstones forming the lower part of the Speckled sandstone series designated as the Conularia beds, because of their containing the fossil *Conularia* enclosed in calcareous concretions The genus *Conularia* is of doubtful systematic position and, like *Hyolithes*, is referred to the Pteropoda, or at times to some other sub-order of the Gastropoda, or even to some primitive order of the Cephalopoda Associated fossils are, *Pleurotomaria*, *Buccania*, *Nucula*, *Pseudomonotis*, *Chonetes*, *Aviculopecten*, etc These fossils are of interest because of their close similarity to the fauna of the Permo-Carboniferous of Australia, which also contains, intercalated at its base, a glacial formation in every respect identical to that of the Talchir series. The Conularia beds are succeeded by a series of mottled or speckled red sandstones, from 300 to 500 feet in thickness, interbedded with red shales. The whole group is current-bedded, and gives evidence of deposition in shallow water. From the mottled or speckled appearance of the sandstone, due to a variable distribution of the colouring peroxide of iron, the group is designated the *Speckled sandstones*

The Productus limestone.

This group is conformably overlain by the Productus limestone, one of the most important formations of India, and one which has received a great deal of attention from Indian geologists, being the earliest fossiliferous rock-system discovered in India. It is exposed in a series of fine cliffs near the Nilawan valley, and thence continues westwards along

CONTORTED CARBONIFEROUS LIMESTONE, NANKSHANG PASS, CENTRAL HIMALAYAS

(C) Overlain by the black Productus shales Notice the unconformable junction between the Carboniferous and Permian, also the fan-taluses at the base of the cliff (*Geol. Survey of India, Mem.* vol. xxiii.)

the Salt-Range right up to the Indus gorge, beyond which it disappears gradually The best and the most accessible outcrops of the rocks are in the Chideru hills in the neighbourhood of Musa Khel, west of the Son Sakesar plateau. The greater part of the Productus limestone is a compact, crinoidal magnesian limestone sometimes passing into pure crystalline dolomite, associated with beds of marl and sandstones. It contains a rich and varied assemblage of fossil brachiopods, corals, crinoids, gastropods, lamellibranchs, cephalopods and plants, constituting the richest Upper Palaeozoic fauna anywhere discovered in India, to which the faunas of the other homotaxial deposits are referred. On palaeontological basis the Productus limestone is divided into three sections . the Lower, Middle and Upper.

With the lower beds of the Lower Productus limestone there comes a sudden change in the character of the sediments, accompanied by a more striking change in the facies of the fauna, almost all the species of the Speckled sandstone group disappearing from the overlying group It is composed of soft calcareous sandstones, full of fossils, with coal-partings at the base. It includes two stages : the lower, more arenaceous stage is well seen at the Amb village, and is known as the Amb beds, and the upper calcareous stage is known as the Katta beds

The Middle is the thickest and most characteristic part of the Productus limestone, consisting of from 200 to 300 feet of blue or grey limestone, which forms the high precipitous escarpments of the mountains near Musa Khel. Dolomite layers, which are frequent, are white or cream-coloured, and from the greater tendency of dolomite to occur in crystalline form they are much less fossiliferous owing to the obliteration of the fossils attending the recrystallisation process. Marly beds are common, and are the best repositories of fossils, yielding them readily to the hammer. The limestones are equally fossiliferous, but the fossils are very difficult to extract, being only visible in the weathered outcrops at the surfaces. Many of the fossils are silicified, especially the corals. Flint and chert concretions are abundantly distributed in the limestones. This division also includes two

stages, Virgal and Kalabagh, the lower part constituting the former stage and the upper the latter

The Upper Productus group is much less thick, hardly reaching 100 feet at places. The group is more arenaceous, being composed of sandstones with carbonaceous shales, with subordinate bands of limestone and dolomite. Silica is the chief petrifying agent here also Fossils are numerous, but they reveal a striking change in the fauna, which separates this group from the preceding group. The most noteworthy feature of this change is the advent of cephalopods of the order *Ammonoidea*, represented by a number of its primitive genera. The topmost stage of the Upper Productus forms a separate stage by itself, known as the Chideru beds They show a marked palaeontological departure from the underlying ones in the greatly diminished number of brachiopods and the increase of lamellibranchs and cephalopods. They are thus to be regarded, from these peculiarities, as a sort of transition or " passage beds " between the Permian and the Triassic. The Chideru beds pass conformably and without any notable change into a series of *Ceratite*-bearing beds of Lower Triassic age.

Productus fauna

The following is a list of the more characteristic genera of fossils belonging to the Productus limestone Many of the genera are represented by a large number of species :

Upper Productus: (Ammonites) *Xenodiscus*, *Cyclolobus*, *Medlicottia*, *Arcestes*, *Sagoceras*; (Brachiopods) *Productus*, *Oldhamina*; (Gastropods) *Bellerophon*, etc.; (Lamellibranchs) *Schizodus*; (Polyzoa) *Entolis*, *Synocladia*, etc.

Middle Productus . (Brachiopods) *Productus*, *Spirifer*, *Spiriferina*, *Athyris*, *Lyttonia*, *Oldhamina*; (Lamellibranchs) *Oxytoma*, *Pseudomonotis*; (Polyzoa) *Fenestella*, *Stenopora*, *Thamniscus*, *Acanthocladia*; (Worm) *Spirorbis*; (Corals) *Zaphrentis*, *Lonsdaleia*; (Gastropods) *Macrocheilus*; (Cephalopods) *Nautilus*, *Orthoceras*.

Lower Productus: *Productus* (*P. cora*, *P. lineatus*, *P. semireticulatus*, *P. spiralis*), *Spirifer*, *Spiriferina*, *Athyris Royssi*, *Orthis*, *Reticularia*, *Richtofenia*, *Martinia*,

Dialesma, *Streptorhynchus*, (Foraminifers) *Fusulina*, *Schwagerina*

[Besides these mentioned above, the following fossils also are characteristic of the Salt-Range Productus limestone.

Gastropods: *Euomphalus*, *Macrocheilus*, *Naticopsis*, *Phaseonella*, *Pleurotomaria*, *Murchisonia*, *Bellerophon* (*Buccania*, *Stachella*, *Euphemus*, and several other genera of the family *Bellerophontidae*), *Hyolithes*

Lamellibranchs *Cardiomorpha*, *Lucina*, *Cardinia*, *Schizodus*, *Aviculopecten*

Brachiopods. These are the most abundant, both as regards species and individuals *Dialesma* is represented by ten species, *Notothyris* (eight species), *Lyttonia* (three species), *Camarophoria* (five species), *Spirigerella* (ten species), *Athyris* (ten species), *Spirifer* (eight species), *Martiniopsis*, *Martinia*, *Reticularia*, *Orthis*, *Strophomena*, *Streptorhynchus*, *Derbeyia* (eight species), *Leptaena*, *Chonetes* (fourteen species), *Strophalosia*, *Productus* (fifteen species), and *Marginifera*.

Polyzoa: *Polypora*, *Goniocladia*, *Thamniscus*.

Crinoids: *Poteriocrinus*, *Philocrinus*, *Cyathocrinus*, etc

Corals: *Pachypora*, *Michelinia*, *Stenopora*, *Lonsdaleia*, *Amplexus*, *Zaphrentis*, *Clisiophyllum*.

Ganoid and other fishes. Plants, etc]

The Productus fauna shows several interesting peculiarities. While the fauna as a whole is decidedly Permian, the presence in it of several genera of true *Ammonites* and of a lamellibranch like *Oxytoma* and a *Nautilus* species, which in other parts of the world are not met with in rocks older than the Trias, gives to it a somewhat newer aspect. The most noteworthy peculiarity, however, is the association of such eminently Palaeozoic forms as *Productus*, *Spirifer*, *Athyris*, *Bellerophon*, etc., with cephalopods of the order *Ammonoidea*. All forms which can be regarded as transitional between the goniatites and the Triassic ceratites are found, including true ammonites like *Cyclolobus*, *Medlicottia*, *Popanoceras*, *Xenodiscus*, *Arcestes*, etc. Some of these possess a simple pattern of *sutures* resembling those of the *Goniatites* (sharply folded) or *Clymenia* (simple zig-zag *lobes* and *saddles*), while others show an

advance in the complexity of the sutures approaching those of some Mesozoic genera.

The Anthracolithic systems of India.

The Salt-Range Productus limestone group is, from fossil evidence, the exact homotaxial equivalent of what is called the "Anthracolithic" (or Permo-Carboniferous) formation of various other parts of India—viz. Kashmir, Spiti and Northern Himalayas generally, and the Shan States of Burma The term "anthracolithic" is used by some authors as a convenient term to express the closely connected Carboniferous and Permian systems of rocks and fossils in these parts of India. Both these systems exhibit, in the various Indian provinces named above, an intimate stratigraphic as well as palaeontological connection with one another, and it is difficult to separate the topmost member of the Carboniferous from the bottom of the Permian.

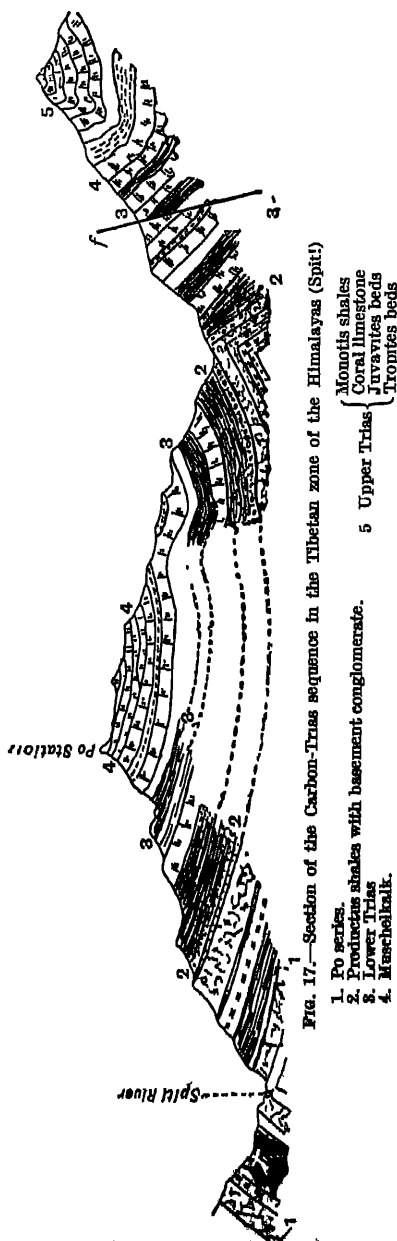
II. THE PERMO-CARBONIFEROUS SYSTEMS OF THE HIMALAYAS

The Himalayan representatives of the Productus limestone are developed in the northern or Tibetan zone of the Himalayas along their whole length from Kashmir to Kumaon and probably beyond They are displayed typically at two localities, Spiti and Kashmir, where they have been studied in great detail by the Geological Survey of India.

Spiti.

In Chapter VIII. we have followed the Palaeozoic sequence of the area up to the Fenestella shales of the Po series. Resting on the top of the Fenestella shales, in our type sections, but at other places lying over beds of varying horizons from the Silurian to the Carboniferous, is a conglomerate layer of variable thickness, belonging in age to the Upper Carboniferous or Permian. This conglomerate, as has been stated before, is an important *datum-line* in India, for it is made the basis of the division of the fossiliferous rock-system of India into two major divisions, the Dravidian and Aryan. The Aryan era, therefore, commences in the Himalayas, with a basement conglomerate, as it commenced in the Salt-Range

FIG. 17.—Section of the Carbon-Trias sequence in the Tibetan zone of the Himalayas (Spiti)

1. Po series.
2. Productus shales with basement conglomerate.
3. Lower Trias
4. Muschelkalk.
5. Upper Trias { Monotis shales, Coral limestone, Juvavites beds, Tropites beds

and in the Peninsula with the glacial boulder-bed.

The conglomerate is succeeded by a group of calcareous sandstones, containing fossil brachiopods of the genus *Spirifer*, *Productus*, *Spiriferina*, *Dialesma* and *Streptorhynchus*, representing the Lower Productus horizon of the Salt-Range. These are overlain by a thin group of dark carbonaceous shales, the characteristic Permian formation of the Himalayas, known as the Productus shales, corresponding to the Upper Productus horizon (See Figs 9 and 17.) The Productus shales are a group of black siliceous, micaceous and friable shales. They are only 100 to 200 feet in thickness, but are distinguished by a remarkable constancy in their lithological composition over the enormous extent of mountains from Kashmir to Nepal. The Productus shales constitute one of the most conspicuous and readily distinguished horizons in the Palaeozoic geology of the Himalayas. Being a soft, earthy deposit, it

The Productus shales.

has yielded most to the severe flexures and compression of this part of the mountains and suffered a greater degree of crushing than the more rigid strata above and below. (See Plate VIII. facing p 100, also Plate XII facing p. 150) The fossil organisms entombed in the shales include characteristic Permian brachiopod species of *Productus* (*P. purdoni*), *Spirifer* (*S musakheylensis*, *S. Rajah*, and five other species), *Spirigera*, *Dialesma*, *Martinia*, *Marginifera* (*M. Himalayensis*) and *Chonetes* Of these the species *Spirifer Rajah* and *Marginifera Himalayensis* are highly characteristic of the Permian of the Central Himalayas. In some concretions contained in the black shales are enclosed ammonites like *Xenaspis* and *Cyclolobus* The Permian rocks of the Central Himalayas have been also designated as the Kuling system from a locality of that name in the Spiti valley.

Dr. Hayden gives the following sequence of Permian strata in the Spiti area ·

Lower Trias.	*Otoceras* zone of Lower Trias.
Permian.	Productus shales: black or brown siliceous shale with *Xenaspis*, *Cyclolobus*, *Marginifera Himalayensis*, etc. Calcareous sandstone with *Spirifer*. Grits and quartzites. Conglomerates (varying in thickness).
Upper Carboniferous.	Fenestella shales of Po series.

The Productus shales are succeeded by a group of beds characterised by the prevalence of the Triassic ammonite *Otoceras*, which denote the lower boundary of the Trias of the Himalayas, one of the most important and conspicuous rock-systems of the Himalayas from the Pamirs to Nepal.

The strata above described mark the beginning of the geosynclinal facies of deposits constituting the northern or Tibetan zone of the Himalayas. As yet the strata are composed of shales and sandstones, indicating proximity of the coast and comparatively shallow waters, but the overlying thick series of Triassic and Jurassic systems are wholly

constituted of limestones, dolomites and calcareous shales of great thickness, giving evidence of the gradual deepening of the ocean bottom.

Kashmir.

In keeping with the rest of the Palaeozoic systems, the Permian is developed on a large scale in Kashmir. A most interesting circumstance in connection with the Permian of Kashmir is the association of both the Gondwana facies of fluviatile deposits containing ferns like *Gangamopteris* and *Glossopteris* and the marine facies containing the characteristic

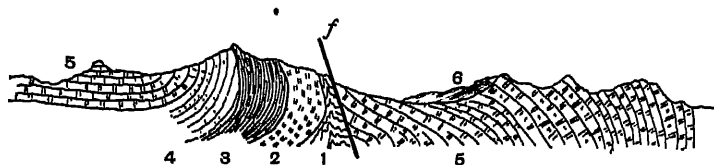



FIG. 18.—Palaeozoic rocks of the N. Shan States

1 Chaung-Magyi series (Cambrian)
2 and 3. Naungkangyi series (Ordovician)
4 Namshim beds (Silurian)
5 Plateau limestone (Devonian and Permo-Carboniferous)
6 Napeng beds (Upper Triassic)

La Touche, *Mem* xxxix. pt. 2, 1913

fossils of the age. The Gondwana beds (known as the *Gangamopteris beds*), which are the local representatives of the Talchir series of the Peninsula, are overlain by the marine Permian beds (*Zewan series*), containing a brachiopod fauna identical in many respects with that of the Productus limestone. (Chap. XXVII. p. 364.)

Burma.

We have seen in Chapter VIII. that there is in Upper Burma (Northern Shan States) a conformable passage of the Devonian and Carboniferous to strata of the Permian age in the great limestone formation constituting the upper part of what is known there as the Plateau limestone. (See also Fig. 10, p. 103.) In the upper beds of these limestones there is present a fauna of brachiopods, corals, polyzoa, etc., which show close relations to the Productus limestone of the Salt-Range and the Productus shales of

the Spiti Himalayas and the Zewan series of Kashmir. From these marked affinities between the homotaxial faunas, Dr. Diener, the author of many palaeontological memoirs on the faunas, considers all these regions as belonging to the same zoo-geographical province

The Permo-Carboniferous rocks of Burma contain two foraminiferal limestones: the Fusulina limestone and the Schwagerina limestone, from the preponderance of these two genera of Carboniferous foraminifers

III. MARINE PERMO-CARBONIFEROUS OF THE PENINSULA.

An extraordinary occurrence has been recorded [1] at Umaria (Central India) of a band of marine Productus limestone in the midst of fresh-water coal-bearing beds belonging to the Barakar stage of the Damuda series (Lower Gondwana system).

The marine intercalation is only a few feet thick and rests quite conformably among the sandstone and grit strata of normal Barakar facies, exposed in a cutting in the Umaria coal-field. The limestone bed is made up entirely of the fossil shells of *Productus*, the only other fossil present being *Spiriferina*.

This bed must be regarded as a solitary record of an evanescent transgression of the sea-waters into the heart of the Peninsula, either from the North through Rajputana, or from the West Coast, induced by some diastrophic modification of the surface of the land, which, however, must have been of a transient nature and must have soon ceased to operate.

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[1] Sinor, K. P., *Mineral Resources of Rewa State*, p 21, 1923.

CHAPTER XII

THE TRIASSIC SYSTEM

General.

THE Productus shales (Kuling system) of the Himalayas and the Chideru stage of the Productus limestone of the Salt-Range are succeeded by a more or less complete development of the Triassic system. The passage in both cases is quite conformable and even transitional, no physical break in the continuity of deposits being observable in the sequence. The Triassic system of the Himalayas, both by reason of its enormous development in the northern geosynclinal zone as well as the wealth of its contained faunas, makes a conspicuous landmark in the history of the Himalayas. The abundance of its cephalopodan fauna is such that it has been the means of a *zonal* classification of the system (*zones* are groups of strata of variable thickness, but distinguished by the exclusive occurrence, or predominance, of a particular species, the zone being designated by the name of the species). In Spiti, Garhwal and Kumaon, and on the north-west extension of the same axis in Kashmir, the Trias attains a development of more than 3000 feet, containing three well-marked sub-divisions, corresponding respectively to the Bunter, Muschelkalk and Keuper of Europe.

Other regions where the Trias occurs, either completely developed or in some of its divisions, are the Salt-Range, Baluchistan and Burma. In the Salt-Range the Triassic system is confined to the Lower Trias and the lower part of the Middle Trias, while in Baluchistan and Burma it is confined to the Upper Triassic stages only. In the two latter areas it assumes an argillaceous facies of shales and slates, whereas in the Himalayan region the system is entirely composed of limestones, dolomites and calcareous shales.

Principles of classification of the geological record.

[With the Trias we enter the Mesozoic era of geology, and before we proceed further we might at this stage enquire into the basis for the classification of the geological record into systems and series, and consider whether the interruptions or "blanks" in the course of the earth's history, which have led to the creation of the chief divisions, in the first instance, in some parts of the world, were necessarily world-wide in their effects and applicable to all parts of the world.

In Europe the geological record is divided into three broad sections or groups: the Palaeozoic, Mesozoic and Cainozoic, representing three great eras in the history of the development of life on the earth, each of which is separated from the one overlying it by an easily perceptible and comparatively wide-spread physical break or "unconformity" Whether these divisions, so well marked and natural in Europe, where they were first recognised, are as well marked and natural in the other parts of the world, and whether these three, with their sub-divisions, should be the fundamental periods of earth-history for the whole world is a subject over which the opinion of geologists is sharply divided. In the geological systems of India, as in the other regions of the earth, although the distinctive features of the organic history of the Palaeozoic, Mesozoic and Cainozoic are clearly evident, as we ascend in the stratigraphic scale, we cannot detect the sharp breaks in the continuity of that history at which one great time-interval ends and the other begins Just at these parts the geological record appears to be quite continuous in India, and any attempt at setting a limit would be as arbitrary as it would be unnatural On the other hand, there are great interruptions or "lost intervals" in the Indian record at other stages (where the European record is quite continuous) at which it is much more natural to draw the dividing lines of its principal divisions—the *groups*. As we have already seen, Sir T H. Holland has accomplished this in his scheme of the classification of the Indian formations. Though generally adopted in India, and best suited to the rather imperfect character of the geological record as preserved in India, such a classification and nomenclature may not be acceptable to those geologists who hold that the grand divisions of geology are universal and applicable to the whole world The subject is difficult to decide one way or the other, but for the information of the student the following view, which summarises the arguments of the former class of geologists with admirable lucidity, is given *verbatim* from the works of Professors T C Chamberlin and R. D. Salisbury [1]

"We believe that there is a natural basis of time-division, that it is recorded dynamically in the profounder changes of the earth's history, and that its basis is world-wide in its applicability. It

[1] *Advanced Geology*, vol. iii. "Earth History."

is expressed in interruptions of the course of the earth's history. It can hardly take account of all local details, and cannot be applied with minuteness to all localities, since geological history is necessarily continuous But even a continuous history has its times and seasons, and the pulsations of history are the natural basis for its divisions.

"In our view, the fundamental basis for geologic time-divisions has its seat in the heart of the earth. Whenever the accumulated stresses within the body of the earth overmatch its effective rigidity, a readjustment takes place. The deformative movements begin, for reasons previously set forth, with a depression of the bottoms of the oceanic basins, by which their capacity is increased The epicontinental waters are correspondingly withdrawn into them The effect of this is practically universal, and all continents are affected in a similar way and simultaneously. This is the reason why the classification of one continent is also applicable, in its larger features, to another, though the configuration of each individual continent modifies the result of the change, so far as that continent is concerned. The far-reaching effects of such a withdrawal of the sea have been indicated repeatedly in preceding pages Foremost among these effects is the profound influence exerted on the evolution of the shallow-water marine life, the most constant and reliable of the means of intercontinental correlation. Second only to this in importance is the influence on terrestrial life through the connections and disconnections that control migration. Springing from the same deformative movements are geographic and topographic changes, affecting not only the land, but also the sea currents. These changes affect the climate directly, and by accelerating or retarding the chemical reactions between the atmosphere, hydrosphere, and lithosphere, affect the constitution of both air and sea, and thus indirectly influence the environment of life, and through it, its evolution. In these deformative movements, therefore, there seems to us to be a universal, simultaneous, and fundamental basis for the subdivision of the earth's history. It is all the more effective and applicable, because it controls the progress of life, which furnishes the most available criteria for its application in detail to the varied rock formations in all quarters of the globe.

"The main outstanding question relative to this classification is whether the great deformative movements are periodic rather than continuous, and co-operative rather than compensatory. This can only be settled by comprehensive investigation the world over; but the rapidly accumulating evidence of great base-levelling periods, which require essential freedom from serious body deformation as a necessary condition, has a trenchant bearing on the question. So do the more familiar evidences of great sea transgressions, which may best be interpreted as consequence of general base-levelling and concurrent sea-filling, abetted by

continental creep during a long stage of body quiescence. It is too early to affirm, dogmatically, the dominance in the history of the earth of great deformative movements, separated by long intervals of essential quiet, attended by (1) base-levelling, (2) sea-filling, (3) continental creep, and (4) sea-transgression; but it requires little prophetic vision to see a probable demonstration of it in the near future. Subordinate to these grander features of historical progress, there are innumerable minor ones, some of which appear to be rhythmical and systematic, and some irregular and irreducible to order. These give rise to the local epochs and episodes of earth-history, for which strict intercontinental correlation cannot be hoped, and which must be neglected in the general history as but the individualities of the various provinces

"The periods which have been recognized in the Palaeozoic and Mesozoic, chiefly on the basis of European and American phenomena, seem to us likely to stand for the whole world, with such emendations as shall come with widening knowledge."]

Trias of Spiti.

The Triassic system of Spiti

Triassic rocks are developed along the whole northern boundary of the Himalayas, constituting the great scarps of the plateau of Tibet, but nowhere on such a scale of perfection as in Spiti and the adjoining provinces of Garhwal and Kumaon (See Figs. 9, 17 and 19) A perfect section of these rocks, showing the relations of the Trias to the system below and above it, is exposed at Lilang in Spiti. From this circumstance the term Lilang system is used as a synonym for the Triassic system of Spiti

The component members of the system are principally dark-coloured limestones and dolomites, with intercalations of blue-coloured shales. The colour, texture, as well as the whole aspect of the limestone, remain uniform over enormous distances without showing local variations. This is a proof of their origin in the clear deep waters of the sea free from all terriginous sediments. The rocks are richly fossiliferous, at all horizons, a circumstance which permits of the detailed classification of the system into stages and zones. The primary division of the Himalayan Trias is into three series, of very unequal dimensions, which, so far as they denote intervals of time, are the exact homotaxial equivalents of the Bunter, Muschelkalk and Keuper series of the European

(Alpine) Trias The following section from Dr. Hayden's *Memoir* gives a clear idea of the classification of the system :[1]

Jurassic : (Rhaetic ?)	Massive Megalodon limestone
Keuper, 2800 ft.	Quartzites with shales and limestones: *Lima, Spirigera.* " *Monotis* shale ". sandy and shaly limestone. Coral limestone *Juvavites* beds · sandstones, shales and limestones. *Tropites* beds . dolomitic limestone and shales. Grey shales . shaly limestone and shales with *Spiriferina, Rhynchonella, Trachyceras,* etc. *Halobia* beds : hard dark limestone with *Halobia, Arcestes,* etc.
Muschelkalk, 400 ft.	*Daonella* limestone : thin black limestone with shales, *Daonella, Ptychites.* Limestone with concretions Grey limestone with *Ceratites, Sibirites,* etc. Nodular limestone (Niti limestone).
Bunter, 50 ft.	Nodular limestone. Limestone and shale with *Aviculopecten.* *Hedenstroemia* zone. *Meekoceras* zone. *Ophiceras* zone. *Otoceras* zone.
Permian :	Productus shales.

Triassic fauna.

The Lower Trias is thin in comparison with the other two divisions of the system, and rests conformably on the top of the Productus shales. The rocks are composed of dark-coloured shales and limestone, with an abundant ammonite fauna. Besides those mentioned in the section above, the following genera are important :

Tirolites, Ceratites, Danubites, Flemingites, Stephanites, with *Pseudomonotis, Rhynchonella, Spiriferina* and *Retzia.*

The middle division is thicker, and largely made up of concretionary limestones. This division is also widespread and capable of detailed subdivision into stages and zones, which preserve a uniform character, both faunistic and lithological, over Spiti, Painkhanda, Byans, and Johar. This division possesses a great palaeontological interest because of the rich Muschelkalk fauna it contains, resembling in many respects the Muschelkalk of the Alps. The Upper Muschelkalk is especially noted for the number and variety of its cephalopod fossils ; it forms indeed the richest and most

[1] "Geology of Spiti," *Mem.*, vol. xxxvi, pt. 1, p. 90.

widely spread fossil horizon in the central and N.W. Himalayas. The most typical fossil belongs to the genus *Ceratites*; besides it there are (Ammonites) *Ptychites*, *Trachyceras*, *Xenaspis*, *Monophyllites*, *Gymnites*, *Sturia*, *Proarcestes*, *Isculites*, *Hollandites*, *Dalmanites*, *Haydenites*, *Pinacoceras*, *Buddhaites* with *Nautilus* (*Sp. Spitiensis*), *Pleuronautilus*, *Syringonautilus* and *Orthoceras*. The brachiopods are *Spiriferina* and *Spirigera*; *Daonella* and *Halobia* are the leading bivalves

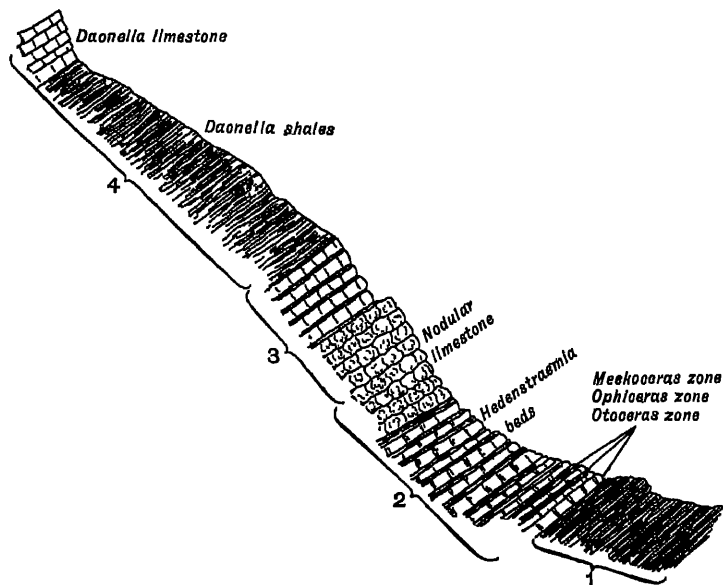



FIG. 19 —Section of the Trias of Spiti

1. Productus shales (Permian).
2. Lower Trias
3. Muschelkalk
4. Upper Trias (lower part only).

Hayden, *Mem G S of India*, vol xxxvi, pl 1

The uppermost division of the Trias is by far the thickest, and is composed of two well-marked divisions—dark shales and marl beds at the lower part, and of thick grey-coloured limestone and dolomite in the upper, with an abundant cephalopodan fauna, whose distribution often characterises well-marked zones The lower of the two divisions corresponds to the Carnic and Noric stages of the Alpine Trias, while the uniform mass of limestones overlying it probably represents the Rhaetic of the Alps.

The faunistic resemblance between the Triassic rocks of the Himalayas and Alps suggests open sea communication maintained by the Tethys between these two areas since the beginning of the Permian. This sea provided a free channel of migration and intercommunication between the marine inhabitants of the central zone of the earth from the Mediterranean shores of France to the eastern borders of China, and maintained this waterway up to the beginning of the Eocene period. The commonest fossils are again: (Ammonites) *Joannites, Halorites, Trachyceras, Tropites, Juvavites, Sagenites, Sirinites, Hungarites, Gymnites Ptychites, Griesbachites* Lamellibranchs are also numerous, the most commonly occurring forms are *Lima, Daonella, Halobia, Megalodon, Monotis, Pecten, Avicula, Corbis, Modiola, Mytilus, Homomya, Pleuromya*, with the addition of the curious genera *Radiolites* and *Sphaerulites* of the *Rudistae* family of the lamellibranchs. The brachiopods are very few, both as regards number and their generic distribution, being confined to *Spirigera, Spiriferina, Rhynchonella*, and their allied forms.

The Triassic fauna shows a marked advance on the fauna of the Productus limestone. The most predominant element of the former is cephalopods, while that of the latter was brachiopods. This is the most noteworthy difference, and signalises the extinction of large numbers of brachiopod families during the interval. This class of the Molluscoidea entered on their decline since the end of the Palaeozoic era, a decline which has steadily persisted up to the present. During the Mesozoic era the brachiopods were represented by three or four genera like *Terebratula, Rhynchonella, Spirigerina*, etc. The place of the brachiopods is taken by the lamellibranchs, which have greatly increased in genera and species. The cephalopods, the most highly organised members of the Invertebrata, will henceforth occupy a place of leading importance among the fauna of the succeeding Mesozoic systems.

Hazara (the Sirban Mountain).

The Trias is found in Hazara occupying a fairly large area in the south and south-east districts of this province, resting unconformably on the great Devonian series of slates and limestone, which have been previously referred to as the Infra-Trias. The Triassic system of Hazara consists, at the base, of about 100 feet of felsitic or devitrified acid lavas of rhyolitic composition, succeeded by a thick formation of

fossiliferous limestone, in which the characteristic Triassic fossils of the other Himalayan areas are present The limestone is thickly bedded, of a grey colour, sometimes with an oolitic structure Its thickness varies from 500 to 1200 feet These rocks form the base of a very complete Mesozoic sequence in Hazara, similar in most respects to that of the geosynclinal zone of the Northern Himalayas, so typically displayed in the sections in the Spiti Valley and in Hundes.

Mt. Sirban.

A locality famous for geological sections in Hazara is Mt. Sirban, a lofty hill lying to the south of Abbotabad. Most of the formations of Hazara are exposed with wonderful

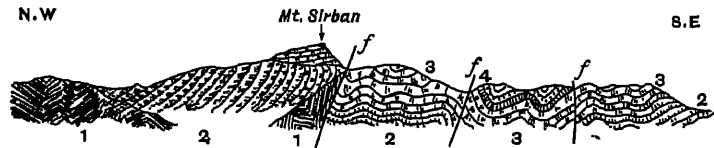



FIG 20.—Diagrammatic section of Mt Sirban, Hazara

1 Slate series (Dharwar) 3 Trias.
2 Infra-Trias (Devonian ?) 4 Jura, Cretaceous

After Middlemiss, *Memoir, Geological Survey of India*, vol xxvi

clearness of detail, in a number of sections along its sides (see Figs. 20 and 21), in which one can trace the whole stratigraphic sequence from the base of the Trias to the Nummulitic limestone. The sections revealed in this hill epitomise in fact the geology of a large part of the North-West Himalayas.[1]

The Trias of the Salt-Range.

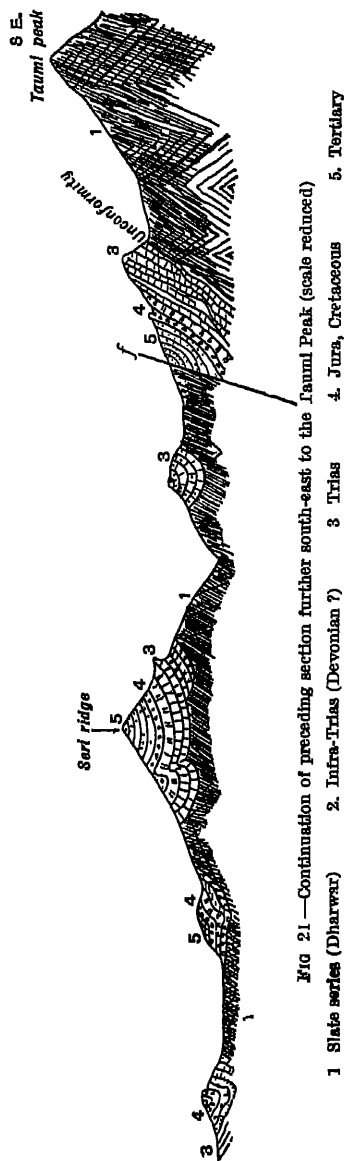
The Ceratite beds.

The Trias is developed, though greatly reduced in its proportion, in the western part of the Salt-Range. The outcrop of the system commences from the neighbourhood of the Chideru hills, and thence continues westward up to a great distance beyond the Indus. It caps the underlying Productus limestone, and accompanies it along a great length of the Range until the disappearance of the latter beyond Kalabagh. The Triassic development of the Salt-Range comprises only the Lower Trias and a small part of the Middle Trias in actual stratigraphic range, but these horizons

[1] *Mem. G.S.I.* vol. ix. pt. 2, 1872, and *Mem. G.S.I.* vol. xxvi, 1896.

are completely developed, and they include all the cephalopod-zones worked out in the corresponding divisions of the Spiti section. On account of the abundance of the fossil ammonite genus *Ceratites* the Lower Trias of the Salt-Range is known as the Ceratite beds The rocks comprising them are about a hundred feet of thin flaggy limestone, which overlie the Chideru stage quite conformably, from which also they are undistinguishable lithologically Overlying beds are grey limestones and marls, nodular at places. Besides *Ceratites,* which are the leading fossils, the other ammonites are *Ptychites, Gyronites, Flemingites,* etc. Fossil shells are found in large numbers in the marly strata, of which the common genera are *Cardinia, Gervillia, Rhynchonella* and *Terebratula.* A very curious fossil in the Ceratite beds is a *Bellerophon* of the genus *Stachella,* the last survivor of the well-known Palaeozoic gastropod. The Ceratite beds are succeeded by about 100 to 200 feet of Middle Trias or Muschelkalk strata, composed of sandstones, crinoidal limestone and dolomites full of cephalopods, whose distribution characterises zones corresponding to the lower portion Middle Trias

FIG 21 —Continuation of preceding section further south-east to the Taumi Peak (scale reduced)

1 Slate series (Dharwar) 2. Infra-Trias (Devonian ?) 3 Trias 4. Jura, Cretaceous 5. Tertiary

of Spiti and Kashmir. Some of the clearest sections of these and younger Mesozoic formations are to be seen in the gullies and nullahs of the Chideru hills of the range. There is a deep ravine near Musa Khel, the Namal gorge, which has dissected the whole breadth of the mountain from Namal to Musa Khel, and the section laid bare in its precipices comprehends the stratified record from the Permian to the Pliocene, with but few interruptions or gaps As one walks along the section to the head of the gorge, one passes in review the rock-records of every succeeding age from the Productus limestone, through

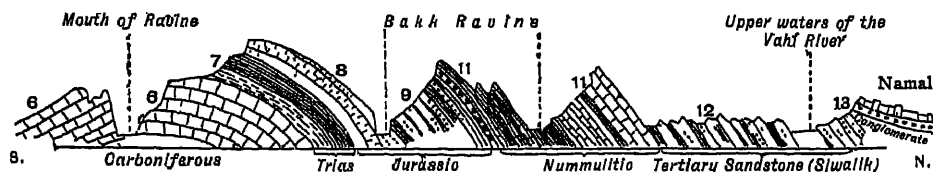



FIG 22 —Section through the Bakk Ravine from Musa Khel to Namal. About natural scale, 3 inches=1 mile

Wynne, "Salt-Range," *Memoir*, vol xiv

the representatives of the Trias, Juras, Eocene and Miocene, to the very top of the Upper Siwalik boulder-conglomerates.

After the Middle Trias there comes a gap in the continuance of the Salt-Range deposits, indicating a temporary withdrawal of the sea from this area. This cessation of marine conditions has produced a blank in its geological history covering the Upper Trias and the early part of the Jurassic period.

Baluchistan.

In the Quetta and Zhob districts of North Baluchistan outcrops of Triassic rocks appear, which are marked by the exclusive prevalence of the uppermost Triassic or Rhaetic stage, no strata referable to the Lower and Middle Trias being found in this province. The rocks are several thousand feet of shales and slates, with a few intercalations of limestone. They contain the Upper Trias species of *Monotis* and a few ammonites like *Didymites*, *Halorites*, *Rhacophyllites*.

The Trias of Baluchistan rests unconformably on an older foraminiferal limestone, Fusulina limestone, of Carboniferous age.

Burma.

A very similar development of the Triassic system, also restricted to the uppermost (Rhaetic or Noric) horizon, occurs in the Arakan Yoma of Burma. The fossils are a few ammonites and lamellibranchs, of which *Halobia* and *Monotis* are the most common.

Napeng series.

Also, what are known as the Napeng beds occur in a number of scattered small outcrops in the Northern Shan States. (See Fig 18, p. 147.) The beds are composed of highly argillaceous, yellow-coloured shales and marls, with a few nodular limestone strata The fossils are *Avicula contorta, Myophoria, Gervillia, Pecten, Modiolopsis, Conocardium,* etc. Although some of these are survivals of Palaeozoic genera, the other fossils leave no doubt of the Triassic age of the strata, while the specific relations of the latter genera suggest a Rhaetic age.[1]

Kashmir.

As is generally the case with the other rock systems, the development of the Trias in Kashmir is on much the same scale as in Spiti, if indeed not on a larger scale A thick series of compact blue limestone and dolomites is conspicuously displayed in many of the hills bordering the valley to the north, while they have entered largely into the structure of the north-east flanks of the Pir Panjal.

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[1] *Mem. G.S.I.* vol. xxxix. pt. 2, 1913.

CHAPTER XIII

THE JURASSIC SYSTEM

Instances of Jurassic development in India.

In the geosynclinal zone of the Northern Himalayas, Jurassic strata conformably overlie the Triassic in a great thickness of limestone and shales. The succession is quite normal and transitional, the junction-plane between the two systems of deposits being not clearly determinable in the type section at Lilang Marine Jurassic strata are also found in the Salt-Range, representing the middle and upper divisions of the system (Oolite). The system is developed on a much more extensive scale in Baluchistan, both as regards its vertical range and its geographical extent A temporary invasion of the sea (marine transgression), over a large part of Rajputana, in the latter part of the Jura gave rise to a thick series of shallow-water deposits in Rajputana and in Cutch. A fifth instance of Jurassic development in India is also the result of a marine transgression on the east coasts of the Peninsula, where an oscillation between marine and terrestrial conditions has given rise to the interesting development of marine Upper Jurassic strata intercalated with the Upper Gondwana formation.

Life during the Jurassic.

Cephalopods, especially the ammonites, were the dominant members of the life of the Jurassic in all the above-noted areas. Although perhaps they reached the climax of their development at the end of the Trias in the Himalayan province, they yet occupied a place of prominent importance among the marine forms of life of this period, and are represented by many large and beautiful forms with highly complex-sutured shells. Lamellibranchs were also very numerous in the Jurassic seas, and held an important position among the

invertebrate fauna of the period. A rich Jurassic flora peopled the land regions of India The lower classes of phanerogams had already appeared and taken the place of the fern and the equisetum of the Permo-Carboniferous periods. The land was also inhabited by a varied population of fish, amphibia and several orders of reptiles, besides the terrestrial invertebrates. We have already dealt with the relics of the latter class of organisms in the description of the Gondwana system.

JURASSIC OF THE CENTRAL HIMALAYAS

Spiti.

Kioto limestone.

In Spiti, Garhwal and Kumaon, the Upper Trias of Noric stage is succeeded by a series of limestones and dolomites of great thickness, the lower part of which recalls the Rhaetic of the Alps, while the upper is the equal of Lias and part of
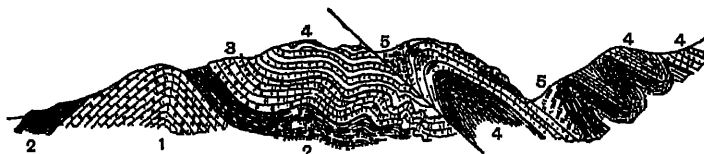
FIG. 23 —Section of the Jurassic and Cretaceous rocks of Hundes

1 Kioto limestone. 4. Cretaceous flysch.
2. Spiti shales. 5. Basic igneous rocks.
3. Giumal sandstone

After Von Krafft, *Mem. G S I* xxxii pt. 3

Oolite. The bottom beds of the series, containing shells of *Megalodon*, pass up into a massive limestone, some 2000 to 3000 feet thick, called the Great limestone, from its forming lofty precipitous cliffs facing the Punjab Himalayas. They are better known under the name of the Kioto limestone. The lithological characters of this limestone indicate the existence of a constant depth of clear water of the sea during its formation. The passage of time represented by this limestone is from Rhaetic to Middle Oolite, as evidenced by the changes in its fauna. The highest beds of the Kioto limestone are fossiliferous, containing a rich fauna of belemnites and lamellibranchs, and are known as the Sulcacutus beds from the preponderance of the species *Belemnites sulcacutus*. The greater part of the Kioto limestone—the middle—is unfossiliferous. A fossiliferous horizon occurs again at the base, containing numerous fossil shells of *Magalodon* and *Dicerocardium*, and hence known as the Megalodon limestone.

Other fossils are *Spirigera, Lima, Ammonites, Belemnites,* with gastropods of Triassic affinities. This lower part of the Kioto limestone is also sometimes designated as the Para stage, while the part above the Megalodon limestone is known as the Tagling stage.

Spiti shales.

The Kioto limestone is overlain conformably by the most characteristic Jurassic formation of the Himalayas, known as the Spiti shales These are a group of splintery black, almost sooty, micaceous shales, about 300 to 500 feet thick, containing numerous calcareous concretions, each of which encloses a well-preserved ammonite shell or some other fossil as its nucleus. (See Fig. 23) The shales enclose pyritous nodules and ferruginous partings, and towards the top, impure limestone intercalations. The whole group is very soft and friable, and has received a great amount of crushing and compression. These black or grey shales show a singular lithological persistence from one end of the Himalayas to the other, and can be traced without any variation in composition from Hazara on the west and the northern confines of the Karakoram range to as far as Sikkim on the east. These Upper Jurassic shales, therefore, are a valuable stratigraphic unit, or "reference horizon," in the geology of the Himalayas, of great help in unravelling a confused or complicated mass of strata, so usual in mountainous regions where the natural order of superposition is obscured by repeated folding and faulting.

Fauna of the Spiti shales.

The Spiti shales are famous for their great faunal wealth, which has made great contributions to the Jurassic geology of the world. The ammonites are the preponderant forms of life preserved in the shales: *Phylloceras, Lytoceras, Hoploceras, Hectioceras, Oppelia, Aspidoceras, Holcostephanus* (=*Spiticeras*, the most common fossil), *Hoplites, Perisphinctes* and *Macrocephalites*. *Belemnites* are very numerous in individuals, but they belong to only two genera, *Belemnites* (*Sp. gerardi*) and *Belemnopsis*. The principal lamellibranch genera are: *Avicula* (*Sp. Spitiensis*), *Pseudomonotis, Aucella, Inoceramus gracilis, Lima, Pecten, Ostrea, Nucula, Leda, Arca* (=*Cucullaea*,) *Trigonia, Astarte, Pleuromya, Cosmomya, Homomya, Pholadomya*; gastropod species belong to *Pleurotomaria* and *Cerithium*.

The fauna of the Spiti shales indicates an uppermost Jurassic age—Portlandian. They pass conformably into the overlying Cretaceous sandstone of Neocomian horizon (Giumal sandstone).

The following table shows in a generalised manner the Jurassic succession of the Central Himalayas:

	Giumal sandstone.	Neocomian (Weald).
Spiti shales (500 ft.).	Lochambel beds. Chidamu beds. Belemnites beds.	Portlandian.
Kioto limestone (3000 ft.).	Sulcacutus beds	Callovian.
	Great thickness of massive limestones, unfossiliferous (Tagling stage).	
	Megalodon limestone (Para stage).	Lias (Rhaetic ?)
	Monotis shale.	Noric.

Eastern Himalayas—Mt. Everest.

Immediately to the north of the crystalline axis of the high range culminating in the peak of Mt. Everest there lies a broad expansive zone of much disturbed and folded Jurassic strata composed of monotonous black shales and argillaceous sandstones, probably the easterly extension of the Spiti shales In the synclinal folds among these are outliers of Cretaceous and Eocene (the Kampa system) rocks, the latter containing *Alveolina* limestone; while underlying the Jurassic shales, and adpressed against the crystalline rocks at the foot of Mt. Everest, is a thick series of metamorphosed fossiliferous limestones of Permo-Triassic age.

The Jurassic shales are unfossiliferous for the most part, but a few obscure *ammonites*, *belemnites* and *crinoids* have been obtained from them. The Permo-Trias limestones contain distorted *Productus* and *Spirifer*.

The schistose flaggy beds which build the peak of Mt. Everest are believed by Dr. A. M. Heron to be altered shales and limestones with sills of granite intruded into them.

Tal series. In the Lesser Himalayas, *i.e.* in the zone lying between the outer Tertiary zone and the inner crystalline zone of the main snow-covered range, and distinguished by the exclusive occurrence in it of highly metamorphosed old (Purana) sediments only, there is noted an exceptional development of a small patch of fossiliferous Jurassic (?) beds underlying the Eocene Nummulitic limestone. This is the only instance of fossiliferous pre-Tertiary rocks being met with south of the central axis of the Himalayas, and is therefore interesting as indicating a slight trespass of the shores of the Tethys beyond its usual south border. The fossils are few and undeterminable specifically; they are fragments of belemnites,

corals and gastropods. These beds, known as the *Tal series*, underlie with a great unconformity older limestones belonging to the Deoban and Krol series of the Purana age

Another instance of a similar nature, and probably belonging to the same age, is met with in the Outer (Kashmir) Himalayas. In the Jammu hills a number of inliers of unfossiliferous Jurassic (?) limestone (the "great limestone") protrude in the midst of Tertiary strata of Sirmur age.

Baluchistan.

Juras of Baluchistan.

Marine Jurassic rocks, of the geosynclinal facies, and corresponding homotaxially to the Lias and Oolite of Europe, are developed on a vast scale in Baluchistan, and play a prominent part in its geology The liassic beds are composed of massive blue or black crinoidal oolitic or flaggy limestone, attaining a thickness of more than 3000 feet, in which the principal stages of the European Lias can be recognised by means of the cephalopods and other molluscs entombed in them. The liassic limestones are overlain by an equally thick series of massive limestone of Oolitic age, which is seen in the mountains near Quetta and the ranges running to the south. The top beds of the last-described limestone contain numerous ammonites, among which the genus *Macrocephalites* attains very large dimensions.

[The rock-systems of Baluchistan are capable of classification into two broad divisions, comprising two entirely different facies of deposits One of these, the Eastern, is mainly characterised by a calcareous constitution and comprises a varied geological sequence, ranging in age from the Permo-Carboniferous upwards This facies is prominently displayed in the mountain ranges of E Baluchistan, constituting the Sind frontier The other facies is almost entirely argillaceous or arenaceous, comprising a great thickness of shallow-water sandstones and shales, chiefly of Oligocene-Miocene age. The latter type prevails in the broad upland regions of W. Baluchistan, stretching from the Mekran coast northwards up to the southward confines of the Helmand desert. These differences of geological structure and composition in the two divisions of Baluchistan have determined in a great measure its principal physical features][1]

All the Mesozoic systems are well represented in East Baluchistan, and are very prominently displayed in the high ground extending from the Takht-i-Suleman mountain to the coast. In the broad arm or gulf of the Tethys which, as we have already stated, occupied Baluchistan almost since

[1] E. W. Vredenburg: *Rec. G.S.I.* vol. xxxviii, p. 63, 1910.

the commencement of its existence, a series of deposits were formed, representative of the ages that followed this occupation Hence the main Mesozoic formations of the Northern Himalayas find their parallels in Baluchistan along a tract of country stretching in a north to south direction.[1]

Hazara.

Spiti shales of Hazara.

The Jurassic system is developed in Hazara, both in the north and south of the province. The two developments, however, are quite distinct from one another, and exhibit a different facies of deposits. The northern exposure is similar both in its lithological and palaeontological characters to the Jura of Spiti, and conforms in general to the geosynclinal facies of Northern Himalayas The Spiti shales are conspicuous at the top, containing some of its characteristic fauna. But the Jurassics of south Hazara differ abruptly from the above, both in their composition and their fossils; they show greater affinity to the Jurassic outcrops of the Salt-Range, which are characterised by a coastal, more arenaceous, facies of deposits. The Spiti shales of the Northern zone have yielded these fossils: *Oppelia, Perisphinctes, Belemnites, Inoceramus, Cucullaea, Pecten, Corbula, Gryphaea, Trigonia*

Burma.

Namyau beds.

Jurassic strata are met with in the Northern Shan States, and are referred to as the Namyau beds, also sometimes designated the Hsipau series. (See Fig. 10, p 103.) The rocks are red or purple sandstones and shales, unfossiliferous in the main, but the lower beds which contain a few limestone bands have yielded a few Jurassic fossils. This group of strata is underlain by shales and concretionary limestones, which have already been referred to as the equivalents of the Rhaetic or Napeng series of Burma.

Salt-Range.

Juras of the Salt-Range.

Middle and upper divisions of the Jurassic are contained in the Salt-Range. The development in the eastern part of

[1] See Vredenburg's "Map of Baluchistan," *Rec. G.S.I.* vol. xxxviii. pt. 3, 1909, and *Pal. Ind.* New Series, vol. iii. mem. 1, 1909—Introduction.

the range is on a small scale, but the system assumes a much greater proportion and homogeneity in the west, trans-Indus, part of the range, especially in the Chichali hills, north-west of Isa Khel, which branches off from the main range at Kalabagh. Indeed this range of hills is composed almost wholly of Jurassic and Eocene (Nummulitic) rocks.

Neglecting the Jurassic development of the Eastern Salt-Range, which is of varying and inconstant lithology, the Jurassic strata of the trans-Indus Range may be summarised in the following table ·

	White sandstones with dark shales, 60 ft. Neocomian fossils.	Cretaceous.
Jurassic strata (500-1500 ft.)	**Upper Jurassic**—light-coloured, thin-bedded highly fossiliferous limestones, and blackish arenaceous shales. Fossils: *Pecten, Lima, Ostrea, Homomya, Pholadomya*, with several *ammonites, belemnites* and gastropods. **Mid Jurassic**—white and variously tinted soft sandstones and clays with lignite and coal-partings; pyritous (alum) shales with subordinate bands of limestone and haematite. Fossils: obscure plant remains—*Ptilophyllum*; *Belemnites, Pleurotomaria, Natica, Mytillus, Ancillaria, Pecten, Myacites, Nerinea, Cerithium, Rhynchonella*, etc.	Mid and Upper Jurassic.
	Ceratite beds, 370 feet.	Triassic.

A section of the above type is seen near Kalabagh on the Indus; a fuller section is visible in the Shekh Budin hills and in the Chichali hills

A few coal or lignite seams occur irregularly distributed in the lower part, and are worked near Kalabagh, which yield on an average about 1000 tons of coal per year; some haematite layers also occur A few beds of a peculiar oolitic limestone, known as the "golden oolite," are found among these rocks. The rock is a coarse-grained limestone, the grains of which are coated with a thin ferruginous layer. Fossil organisms preserved in these rocks, besides those named in the section above, are: *Ostrea, Exogyra*, species of *Terebratula*, numerous

gastropods, *Ammonites* and *Belemnites*. The spines of numerous large species of echinoids, like *Cidaris*, and fragments of the tests of *irregular* echinoids, are frequent in the limestones.

A rapidly varying lithological composition of a series of strata, such as that of the Jurassic of the Salt-Range, is suggestive of many minor changes during the course of sedimentation in that area; such, for instance, as changes in the depth of the sea, or of the height of the lands which contribute the sediments, of alterations in the courses of rivers, and of the currents in the sea, etc.

FIG 24.—Sketch section in the Chichali Pass
Wynne, *Mem Geological Society of Indus*, vol. xiv.

[It is in the west and trans-Indus part of the Salt-Range that the Mesozoic group is developed in some degree of completeness. In the eastern, cis-Indus part, with the exception of the Triassic Ceratite beds, the Mesozoic group is incompletely developed and irregularly distributed.

The *structure* of this part of the Salt-Range offers a striking contrast to that of the part east of the Indus. It is one of colossal disturbance, by which the stratigraphy of the mountains is completely obscured, a condition so different from what is met with in the eastern part. The strata by repeated folding and faulting have acquired such a confused disposition that the natural order of superposition is altogether subverted, while the faulted and tilted blocks lie against one another in the most intricate disorder imaginable.]

Marine Transgressions during the Jurassic period.

After the emergence of the Peninsula at the end of the Vindhyan system of deposits, this part of India has generally remained a land area, a continental tableland exposed to the denuding agencies. No extensive marine deposits of any subsequent age have been formed on the surface of the Peninsula since that early date.

Nature of marine transgressions

In the Jurassic period, however, several parts of the Peninsula, viz. the coasts and the low-lying flat regions in the interior, like Rajputana, were temporarily covered by the seas which invaded the lands. These temporary encroachments of the sea over what was previously dry land are not uncommon in the records of several geological periods, and are caused by the sudden decrease in the capacity of the ocean basin by some deformation of the crust, such as the sinking of a large land-mass, or the elevation of a submarine tract Such invasions of the sea on land, known as "marine transgressions," are of comparatively short duration and invade only low level areas, converting them for the time into epicontinental seas The series of deposits which result from these transgressions are clays, sands or limestones of a littoral type, and constitute a well-marked group of deposits, sometimes designated by a special name—the Coastal system. One example of the coastal system we have already seen in connection with the Upper Gondwana deposits of the East Coast. The remaining instances of marine transgressional deposits in the geology of India are the Upper Jurassic of Cutch and Rajputana ; the Upper Cretaceous of Trichinopoly, of the Narbada valley and of the Assam hills, the Eocene and Oligocene of Gujarat and Kathiawar, and the somewhat newer deposits of a number of places on the Coromandel coast.

Deposits which have originated in this manner possess a well-defined set of characters, by which they are distinguishable from the other normal marine shallow-water deposits (1) Their thickness is moderate compared to the thickness of the ordinary marine deposits, or of the enormous thickness of the geosynclinal formations ; (2) they, as a rule, cover a narrow strip of the coast only, unless low lands extend

farther inland, admitting the sea to the interior; (3) the dip of the strata is irregular and sometimes deceptive, owing to current-bedding and deposition on shelving banks Generally the dip is seaward, away from the main land; consequently the oldest beds are farthest inland while the newest are near the sea In some cases, however, a great depth of deposition is possible during marine transgressions, as when tracts of the coast, or the continental shelf, undergo sinking, of the nature of trough-faulting, concurrently with deposition. Such was the case, for instance, with the basins in which the Jurassics of Cutch were laid down, in which the sinking of the basins admitted of a continuous deposition of thousands of feet of coastal detritus Such block-faulting is quite in keeping with the horst-like nature of the Indian Peninsula, and belongs to the same system of movements as that which characterised the Gondwana period.

Cutch.

The Jurassics of Cutch

Jurassic rocks occupy a large area of the Cutch State. It is the most important formation of Cutch both in respect of the lateral extent it covers and in thickness With the exception of a few small patches of ancient crystalline rocks, no older system of deposits is met with in this area It is quite probable, however, that large parts of the country which at the present day are long, dreary wastes of black saline mud and silt (the Rann) are underlain by a substratum of the Peninsular gneisses together with the *Puranas*. A broad band of these rocks extends in an east-west direction along the whole length of Cutch, and they also appear farther north in the islands in the Rann of Cutch. The main outcrop attenuates in the middle, owing to the overlap of the younger deposits. The aggregate thickness of the formation is over 6000 feet, a depth quite incompatible with deposits of this nature, but for the explanation given above.

The large patch of Jurassic rocks in East Kathiawar around Dhrangadhra belongs to the same formation, and is an outlier of the latter on the eastern continuation of the same strike.

The Jurassics of Cutch include four series—*Patcham*, *Chari*,

Katrol and *Umia*, in ascending order, ranging in age from Lower Oolite to Weald. The base of the system is not exposed, and the top is unconformably covered either by the Cretaceous basalts of the Deccan Trap formation or by Nummulitic beds (Eocene)

The following table, adapted from Dr Oldham, gives an idea of the stratigraphic succession

Series	Beds	Age
Umia (3000 ft.).	Marine sandstones with *Crioceras*, etc., sandstone and shale with cycads, conifers, and ferns (Gondwana facies) Marine sandstone and conglomerate with *Perisphinctes* and *Trigonia*.	Weald.
Katrol (1000 ft.).	Sandstone and shale with *Perisphinctes* and *Oppelia*. Ferruginous red and yellow sandstone (*Kantkote* sandstones) with *Stephanoceras*, *Aspidoceras*.	Upper Oolite.
Chari (1100 ft.)	Dhosa oolite, oolite limestone, *Peltoceras*, *Aspidoceras*, *Perisphinctes*. White limestones; *Peltoceras*, *Oppelia*. Shales with ferruginous nodules, *Perisphinctes*, *Harpoceras* Shales with "golden oolite"; *Macrocephalites*, *Oppelia*.	Middle Oolite.
Patcham (1000 ft.).	Grey limestones and marls with *Oppelia*, corals, brachiopods, etc. Yellow sandstones and limestones with *Trigonia*, *Corbula*, *Cucullaea*, etc Base not seen.	Lower Oolite.

Patcham series. The lowest member, Patcham series, occurs in the Patcham island of the Rann, as well as in the main outcrop in Cutch proper The lower beds are exposed towards the north, and are visible in many of the islands. The strata show a low dip to the south, *i e.* seawards The constituent rocks are yellow-coloured sandstones, and limestones, overlain by limestones and marls. The fossils are principally ammonites and lamellibranchs, the leading genera being *Trigonia*, *Lima*, *Corbula*, *Gervillaea*, *Exogyra*, and *Oppelia*, *Perisphinctes*, *Stephanoceras*; some species of *Nautilus*

Chari series. The Chari series takes its name from a village near Bhuj, from where an abundant fauna corresponding with that of the Callovian stage of the European Jura has been obtained. It is composed of shales and limestones, with a peculiar red or

brown, ferruginous, oolite limestone, known as the *Dhosa oolite*, at the top There also occur, at the base, a few bands of what is known as the golden oolite, a limestone composed of rounded calcareous grains coated with iron and set in a matrix. The chief element of the fauna is cephalopods, one hundred species of ammonites being recognisable in them. The principal genera are: *Perisphinctes, Phylloceras, Oppelia, Macrocephalus, Harpoceras, Peltoceras, Aspidoceras, Stephanoceras.* In addition there are three or four species of *Belemnites*, several of *Nautilus*, and a large number of lamellibranchs. The Chari group is palaeontologically the most important group of the Jurassic of the Cutch, because it has furnished the greatest number of fossil species identical with known European types; the Dhosa oolite, coming at the top of the Chari series, is the richest in ammonites

The Katrol series

The Chari series is overlain by the Katrol group of shales and sandstones The shales are the preponderant rocks of this series, forming more than half its thickness The sandstones are more prevalent towards the top The shales are variously tinted by iron oxides, which at places prevail to such an extent as to build small concretions of haematite or limonite. The Katrol series forms two long wide bands in the main outcrop in Cutch; the exposure where broadest is ten miles wide. Besides forms which are common to the whole system the Katrol series has, as its special fossils, *Harpoceras, Phylloceras, Lytoceras,* and *Aptychus.* A few plants are preserved in the sandstone and shale beds, but in such an imperfect state of fossilisation that they cannot be identified and named.

The Umia series

Over the Katrol group comes the uppermost division of the Cutch Jura, the Umia series, comprising a thickness of 3000 feet of soft and variously coloured sandstones and sandy shales. The lower part of the group is conglomeratic, followed by a series of sandstone strata in which the fossils are rare except two species of *Trigonia, T. ventricosa* and *T. Smeei,* which are, however, very typical. Over this there comes an intervening series of strata of sandstones and shales, which, both in their lithological as well as palaeontological relations, are akin to the Upper Gondwana rocks of the more easterly

parts of the Peninsula. The interstratification of these beds with the marine Jurassic should be ascribed to the same circumstances as that which gave rise to the marine intercalations in the Upper Gondwana of the east coast. After this slight interruption the marine conditions once more established themselves, because the higher beds of the Umia series contain many remains of ammonites and belemnites. The Umia group has wide lateral extent in Cutch, its outcrop being much the broadest of all the other series. Its breadth, however, is considerably reduced by the overlapping of a large part of its surface by the Deccan Traps and still younger beds The fossils yielded by the Umia series are: species of *Alethopteris*, *Taeniopteris*, *Cycads* and *Conifers*, which have been enumerated in the chapter relating to the Upper Gondwana. The marine fossils include the genera *Crioceras*, *Acanthoceras*, *Belemnites*, with *Trigonia smeei* and *Trigonia ventricosa*.

The rocks above described are traversed by an extensive system of trap dykes and sills and other irregular intrusive masses of large dimensions. In the north they become very complex, surrounding and ramifying through the sedimentary beds in an intricate net-work The intrusions form part of the Deccan Trap series and are its hypogene roots and branches.

The Jurassic outcrop of North-East Kathiawar, already referred to, is composed of soft white or ferruginous sandstones and pebble-beds or conglomerates In this respect, as well as in its containing a few plant fossils, it is regarded to be of Umia horizon. The sandstone is a light-coloured freestone, largely quarried at Dhrangadhra for supplying various parts of Gujarat with a much-needed building material.

Rajputana.

Jurassic of Rajputana.

The inroads of the Jurassic sea penetrated much farther than Cutch in a north-east direction, and overspread a great extent of what is now Rajputana. Large areas of Rajputana received the deposits of this sea, only a few patches of which are exposed to-day, from underneath the sands of the Thar desert. It is quite probable that a large extent of fossiliferous rocks, connecting these isolated inliers, is buried under the desert sands.

Fairly large outcrops of Jurassic rocks occur in Jaisalmer and Bikaner. They have received much attention on account of their fossiliferous nature A number of divisions have been recognised in them, of which the lowest is known as the Balmir sandstone; it is composed of coarse sediments—grits, sandstones and conglomerates with a few badly preserved remains of dicotyledonous wood and leaves The next group is distinguished as the Jaisalmer limestone, composed of highly fossiliferous limestones with dark-coloured sandstones. The limestones have yielded a number of fossils, among which the more typical are *Pholadomya, Corbula, Trigonia costata, Nucula, Pecten, Nautilus* and some *Ammonites*. This stage is regarded as homotaxial in position with the Chari series of Cutch

The Jaisalmer limestone is overlain by a series of rocks which are referred to three distinct stages in succession. The rocks are red ferruginous sandstones, succeeded by a soft felspathic sandstone, which in turn is succeeded by a group of shales and limestones, some of which are fossiliferous

Dr. La Touche, of the Geological Survey of India, has assigned a younger age to the Balmir beds (Cretaceous), mainly from the evidence of the dicotyledonous plant fossils which they contain.

Jurassic rocks are also exposed in the southern part of Rajputana, where a series of strata bearing resemblance to the above underlie directly Nummulitic shale beds of Eocene age.

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CHAPTER XIV

THE CRETACEOUS SYSTEM

Varied facies of the Cretaceous

No other geological system shows a more widely divergent facies of deposits in the different areas of India than the Cretaceous, and there are few which cover so extensive an area of the country as the present system does in its varied forms The marine geosynclinal type prevails in the Northern Himalayas and in Baluchistan, and the marine shallow-water in the Salt-Range, parts of the Coromandel coast bear the records of a great marine transgression during the Cenomanian Age, while right in the heart of the Peninsula there exists a chain of outcrops of marine Cretaceous strata along the valley of the Narbada A fluviatile facies is exhibited in a series of wide distribution in the Central Provinces and the Deccan. An igneous facies is represented, in both its intrusive and extrusive phases, by the records of a gigantic volcanic outburst in the Peninsula, and by numerous intrusions of granites, gabbros and other plutonic rocks in many parts of the Himalayas, Burma and Baluchistan.

The geography of India in the Cretaceous period.

This heterogeneous constitution of the Cretaceous is proof of the prevalence of very diversified physical conditions in India at the time of their formation, and the existence of quite a different order of geographical features. The Indian Peninsula yet formed an integral part of the great Gondwana continent, which was still an unbroken land-mass stretching from Africa to Australia. This mainland completely divided the seas of the south and east from the great central ocean, the Tethys, which kept its hold over the entire Himalayan region and Tibet, cutting off the northern continents from the southern hemisphere. A deep gulf of this sea occupied the Salt-Range, Western Sind, Baluchistan and overspread Cutch, and at

one time it penetrated to the very centre of the Peninsula by a narrow inlet through the present valley of the Narbada The southern sea at the same time encroached on the Coromandel coast, and extended much further north, overspreading Assam and probably flooding a part of the Indo-Gangetic depression. It is a noteworthy fact that no communication existed between these two seas—of Assam and the Narbada valley—although separated by only a small distance of intervening land.

While such was the geography of the rest of India the north-west part of the Peninsula was converted into a great centre of vulcanicity of a type which has no parallel among the volcanic phenomena of the modern world. Hundreds of thousands of square miles of the country between Southern Rajputana and Dharwar, and in breadth almost from coast to coast were inundated by basic lavas which covered, under thousands of feet of basalts, all the previous topography of the country, and converted it into an immense volcanic plateau.

We shall consider the Cretaceous system of India in the following order :

(i) *Cretaceous of the Extra-Peninsula :*
- N. Himalayas, Spiti, Kashmir, Hazara.
- Sind and Baluchistan.
- Assam.
- Burma.

(ii) *Cretaceous of the Peninsula :*
- Trichinopoly Cretaceous.
- Narbada Valley Cretaceous.
- Lameta series.

(iii) *Deccan Traps.*

CRETACEOUS OF THE NORTHERN HIMALAYAS

Spiti.

That prominent Upper Jurassic formation, the Spiti shales, Giumal sandstone of the Northern ranges of the Himalayas constituting the

Tibetan zone of Himalayan stratigraphy is overlain at a number of places by yellow-coloured siliceous sandstones and quartzites known as the Giumal sandstone. (See Fig. 23.) In the Spiti area the Giumal series has a thickness of about 300 feet. The deep and clear waters of the Jurassic sea, in which the great thickness of the Kioto limestone was formed, had shallowed perceptibly during the deposition of the Spiti shales. The shallowing became more marked with the deposits of the next group. These changes in the depth of the sea are discernible as much by a change in the characters of the sediments as by changes in the fauna that are preserved in them. The deeper-water organisms have disappeared from the Giumal faunas, except for a few colonies where deep local basins persisted The fossil organisms entombed in the Giumal sandstone include: (Lamellibranchs) *Cardium, Ostrea, Gryphaea, Pecten, Tellina, Pseudomonotis, Arca, Opis, Corbis, Cucullaea, Tapes*; (Ammonites) *Holcostephanus, Hoplites*

Chikkim series

The Giumal series is succeeded in the area we are considering at present by a group of about 250 feet of white limestones and shales Fossils are found only in the limestones which underlie the shales. This group is known as the Chikkim series, from a hill of that name in Spiti. The Chikkim series is also one of wide horizontal prevalence, like the Spiti shales, outcrops of it being found in Kashmir, Hazara, Afghanistan and Persia. The fossils that are preserved in the limestone are fragments of the guards of *Belemnites*, shells of the peculiar lamellibranch genus *Hippurites* (belonging to the family *Rudistae*) and a number of foraminifers, *e.g. Nodosaria, Cristellaria, Textularia, Dentallina*, etc., congeners of the foraminifers whose tiny shell-cases have built up the chalk of Europe. In the neighbouring areas of Spiti the Chikkim series is overlain by a younger series of Cretaceous rocks, composed of a great thickness of unfossiliferous sandstones and sandy

Flysch

shales of the type to which the name of *Flysch*[1] is applied.

[1] The typical Flysch is a Tertiary formation of Switzerland, and is composed mainly of soft sandstones, marls, and sandy shales covering a wide extent of the country. Its age is Eocene or Oligocene Fossils are rare or absent altogether. The term is, however, applicable to similar deposits in other countries also and of other ages than Eocene or Oligocene.

(See Fig 23.) The Cretaceous flysch gives further evidence of the shallowing of the Tethys and its rapid filling up by the coarser littoral detritus With the flysch deposits the long and uninterrupted geosynclinal conditions approached their end, and the Chikkim series may be regarded as the last legible chapter in the long history of the Himalayan marine period. The flysch deposits that followed mark the gradual emergence of land, and the receding of the shore-line further and further north. The Himalayan continental period had already begun and the first phase of its uplift into the loftiest mountain-chain of the world commenced, or was about to commence.

In the general retreat of the Tethys from the Himalayan province at this period, a few scattered basins were left at a few localities, *e g.* at Hundes and Ladakh. In these areas the sea retained its hold for a time, and laid down its characteristic deposits till about the middle of the Eocene, when further crustal deformations drove back the last traces of the sea from this part of the earth.

IGNEOUS ACTION DURING CRETACEOUS

Plutonic and volcanic action.

The history of the latter part of the Cretaceous age, and the ages that followed it immediately, are full of the proofs of widespread igneous action on a large scale, both in its plutonic as well as in its volcanic phase. An immense quantity of magma was intruded in the pre-existing strata, as well as ejected at the surface over wide areas in Baluchistan, the North-West Himalayas, Kumaon Himalayas and Burma. Masses of granites, gabbros and peridotites cut through the older rocks in bosses and veins, laccolites and sills, while the products of volcanic action (lava-flows and ash-beds) are found interstratified in the form of rhyolitic, andesitic and basaltic lava sheets and tuffs. The ultrabasic, peridotitic intrusions of these and slightly subsequent ages are at the present day found altered into serpentine-masses bearing some useful accessory products that have been separated from them by the process of magmatic segregation. Of these the most important are the chromite masses

in Baluchistan and the semi-precious mineral jadeite in Burma.

A great proportion of the granite which forms such a prominent part of the crystalline core of the Himalayas, forming the broad central belt between the outer Tertiary zone and the inner Tibetan zone, is also referred, in a great measure, to the igneous activity of this age. Three kinds of granites are recognised in the Himalayan central ranges, viz. Biotite-granite, which is the most widely prevalent, Hornblende-granite and Tourmaline-granite, but it is quite probable that all the three have been derived by the differentiation of one originally homogeneous magma

As will be alluded to later, this outburst of igneous forces is connected with the great physico-geographical revolutions of the early Tertiary period, revolutions which culminated in obliterating the Tethys from the Indian region and the severing of the Indian Peninsula from the Indo-African Gondwana continent

"Exotic" Blocks of Johar.

The records of an extraordinary volcanic phenomenon are witnessed in connection with the Cretaceous rocks of the Kumaon Himalayas Lying over the Cretaceous rocks of Johar, on the Tibetan frontier of Kumaon, are a number of detached blocks of sedimentary rocks of all sizes from ordinary boulders to blocks of the dimensions of an entire hill-mass. These lie in a confused pell-mell manner, in all sorts of stratigraphic discordance on the underlying beds. From the evidence of their contained fossils these blocks are found to belong to almost every age, from early Permian to the newest Cretaceous. But the fossils reveal another, more curious fact, that these rock-masses do not belong to the Spiti facies of deposits, but are of an entirely foreign facies prevailing in a distant northern locality in Upper Tibet. Such a group of "exotic" or foreign blocks of rocks, out of all harmony with their present environments, were at first believed to be the remnants of denuded recumbent folds, or were ascribed to faulting, and were considered as identical with the "Klippen" of the Alps. But from the circumstance of the close association, and sometimes even intermixing of these blocks with volcanic products like basalts and andesites,

an altogether novel method of origin has been suggested, viz that these blocks were torn by a gigantic volcanic explosion in North Tibet (such as is connected with the production of volcanic agglomerates and breccias), and subsequently transported in the lava inundation to the positions in which they are now found. The mode in which these blocks are scattered in the most confused disorder imaginable, is in agreement with the above view of their origin. These foreign, transported blocks on the Kumaon frontier are known in Himalayan geology as the exotic blocks of Johar Similar phenomena are recorded in other parts of the Himalayas as well.

Hazara.

Representatives of the Giumal sandstone are found in Hazara capping the Spiti shales, in a group of dark-coloured, close-grained, massive sandstones. The Giumal sandstone passes up into a very thin arenaceous limestone only some 10 to 20 feet thick, but containing a suit of fossils possessing affinities with the English *Gault* The leading fossils are ammonites, of typically Cretaceous genera, like *Acanthoceras* (in great numbers), *Ancyloceras*, *Anisoceras*, *Baculites*, etc., the latter forms being characterised by possessing an uncoiled shell. There are also many *Belemnite* remains. The Cretaceous limestone is overlain by a great development of the Eocene system—the Nummulitic limestone—much the most conspicuous rock-group in all parts of the Hazara province.

Sind and Baluchistan.

Cretaceous of Sind.

Upper Cretaceous rocks indicating the Campanian and Maestrichtian horizons (Upper Chalk) are developed in Sind in one locality only, the Laki range. The bottom beds are about 300 feet of whitish limestones, containing echinoids like *Hemipneustes*, *Pyrina*, *Clypeolampas*, and a number of molluscs. Among the latter is the genus *Hippurites*, so characteristic of the Cretaceous period in all parts of the world. This hippurite limestone is a local representative of the much more widely developed hippurite limestone of Persia, which is prolonged into south-eastern Europe through Asia Minor. It is succeeded by a group of sandstones and shales, often highly

ferruginous, some beds of which contain ammonites like *Indoceras, Pachydiscus, Baculites, Sphenodiscus,* etc. These are in turn overlain by fine, green arenaceous shales and sandstones, unfossiliferous and of a flysch type, attaining a great thickness An overlying group of sandstone is known as the Pab sandstone. The top beds of this sandstone consist of olive-coloured shales and soft sandstones, the former of which are highly fossiliferous, the commonest fossil being *Cardita beaumonti*, a lamellibranch with a highly globose shell. This group is designated the *Cardita beaumonti beds.* Other fossils include *Ostrea, Corbula, Turritella, Natica, Lytharea, Caryophylla, Smilotrochus*, and other corals; echinoderms, gastropods and some *vertebrae* belonging to a species of Crocodiles. The Cardita beds are both interstratified as well as overlain by sheets of Deccan Trap basalts, one band of which is nearly 100 feet thick, of amygdaloidal basalt. The age of the Cardita beds, from the affinities of their contained fossils, is regarded as uppermost Cretaceous (Danian).

Cardita beaumonti beds

Cretaceous of Baluchistan

The Cretaceous system as found developed in Baluchistan is on a much more perfect scale than in Sind, covering a far wider extent of the country and attaining a greater thickness In this area, moreover, the Lower Cretaceous of Weald and Greensand ages are also represented These horizons are recognised in a series of shales and limestones resting upon the Jurassic rocks of Baluchistan, known respectively as the *Belemnite shales* and the *Parh limestone.* The lower, belemnite beds are a series of black shales crowded with the *guards* of belemnites. They are overlain by a conspicuous thick mass of variously coloured siliceous limestones, 1500 feet in thickness, extending from the neighbourhood of Karachi to beyond Quetta in one almost continuous outcrop. This division is known as the Parh limestone. The Parh limestone is in the main unfossiliferous except for a few shells, e g *Inoceramus, Hippurites,* and some corals.

The Upper Cretaceous sequence of Baluchistan rests with a slight unconformability on the eroded surface of the Parh limestone. This sequence is broadly alike in Sind and Baluchistan, and the account given above applies to both. In Baluchistan, however, the flysch deposits are found

developed on a larger scale than in Sind, and form a wider expanse of the country. They are distinguished as the *Pab sandstone* from the Pab range in Baluchistan. The upper beds of the Pab sandstone are the equivalents of the Cardita beaumonti beds of Sind.

The Upper Cretaceous of both Sind and Baluchistan, especially the Cardita beaumonti beds, is largely associated with volcanic tuffs and basalts, the local representatives of the Deccan Traps of the Peninsula. In Baluchistan there are also large bosses and dykes of gabbros and other basic plutonic rocks piercing through strata of this age

It should be noticed that the upper parts of the Umia beds described with the Jurassic rocks of Cutch are of Lower Cretaceous age—Weald.

Salt-Range.

The Cretaceous system is very inconspicuously developed in the trans-Indus extension of this range (see Fig 24), it being, but for a few beds containing *Cardita beaumonti*, entirely absent in the cis-Indus portion. A small thickness of Cretaceous rocks is met with on the Chichali range resting over the Jurassic and covered conformably by the Eocene. The rocks are white and yellow sandstones and shales, among which are some beds of black shales, which contain ammonites of Neocomian affinities—*Perisphinctes asterianus* being the common form.

Assam.

The Cretaceous system of deposits is prominently seen in the Assam ranges, where the horizontally-bedded sandstones unconformably overlie the deeply eroded edges of the *Shillong quartzites*, or the other metamorphics of Assam. They are in turn conformably overlain by the Eocene nummulitic limestone. The Cretaceous series is well seen in the southern scarps of the plateau of Shillong , it is likewise well seen in the Garo hills.

A constant member of the Assam Cretaceous series is a band of hard coarse sandstone, 200 feet thick, mostly unfossiliferous, except for a few carbonised vegetable remains. This is directly sub-nummulitic in position and is designated as the *Cherra Sandstone* ; at its base is a quartzitic conglomerate. In addition to the above, a few fossil-bearing strata of marine origin are present, together with carbonaceous matter irregularly distributed in a few coal-seams. In the neighbourhood of Cherrapunji some outcrops of these rocks

have yielded a number of fossils, of which the leading genera are: *Baculites, Gryphaea, Pecten, Nerita, Spondylus, Inoceramus, Rostellaria, Turritella,* etc, together with many *plant* remains. The component rocks are littoral conglomerates and coarse unfossiliferous sandstones, with a few calcareous beds which contain the fossils. The organic remains of this group of beds, as well as their petrological constitution, prove their identity with the much better known and more perfectly studied Cretaceous of the south-east coast. Many species are common to these areas, and they must have lived in the same sea and along a continuous coast-line allowing of a free migration of the animals.

The Cretaceous also occur in the Garo hills on a considerable scale. The sandstones assume great thickness, enclosing at places important coal-seams. In both the Khasi and Garo hill Cretaceous the stratification is quite horizontal, a characteristic shared by all the later formations.

Burma.

In the Arakan Yoma of Burma, and in the southward continuation of the same strike, in the Andaman Islands, Cretaceous beds are found They reveal no connection with the Cretaceous of Assam, but exhibit a marked analogy with Sind and Baluchistan. The lower Cretaceous Parh limestone and the upper flysch-like unfossiliferous sandstones and shales, capped by the Cardita beaumonti beds with trappean intercalations and ash-beds (equivalents of Deccan Traps), are all recognised in the Arakan range and further south. There are no marine Cretaceous rocks in Burma east of the Irrawaddy.

Among the intrusive Cretaceous rocks of Burma are masses of serpentines traversed by veins of jadeite, which yield the jadeite of commerce for which Burma is famous.

Chitral.

In the Chitral area the Middle Cretaceous is represented by *Hippurites* limestone and *Orbitolites* limestone in narrow faulted bands which run along the general strike of the country. These pass upwards into the Reshun conglomerate of Upper Cretaceous or Lower Tertiary age.[1]

Further evidence of distinctly intrusive nature of extensive belts of granitoid gneiss of the Central Himalayan Gneiss facies has been recorded by Tipper in Chitral. Numerous bosses of granite are found to have invaded Mesozoic strata in some cases inferred, on fossil evidence, to be of Jurassic age.

[1] G H. Tipper, *Rec. G.S I* vol. lv. p 38, and vol. lvi. pp. 44-48.

CHAPTER XV

THE CRETACEOUS SYSTEM (*Continued*)

PENINSULA

Upper Cretaceous of the Coromandel coast

UPPER Cretaceous rocks of the south-east coast of the Peninsula form one of the most interesting formations of South India, which have been studied in great detail by many geologists and palaeontologists. They are a relic of the great marine transgression of the Cenomanian Age, whose records are seen in many other parts of the world, besides the coasts of the Gondwana continent in India as well as Africa Three small inliers of these rocks occur among the younger Tertiary and Post-Tertiary formations which cover the east coast of the Peninsula Their bottom beds rest either upon a basement of the ancient Archaean gneisses or upon the denuded surface of some division of the Upper Gondwana. As is usual with deposits formed during transitory inroads of the sea, as mentioned in a previous chapter, the dip of the strata is towards the east, hence the outcrops of the youngest stage occur towards the sea, while the older beds are seen more towards the interior of the mainland.

Interest of the south-east Cretaceous.

South of Madras these rocks are exposed in three disconnected patches, in which all the divisions of the Cretaceous from Cenomanian (Lower Chalk) to Danian (uppermost Cretaceous) are present. The most southerly outcrop, viz. that in the vicinity of Trichinopoly, has an area of from two to three hundred square miles, while the other two are much smaller But the fauna preserved in these outcrops is of remarkable interest and of inestimable value alike on account

of the multitude of genera and species of an old-world creation that are preserved, and for the perfect state of their preservation. Sir T. H Holland speaks of these three small patches of rocks as forming a little museum of palaeozoology, containing more than 1000 species of extinct animals, including forms which throw much light on the problem connected with the distribution of land and sea during the Cretaceous Their distribution and their relations to the Cretaceous fauna of the other Indian and African regions have much to tell about the geography of the Gondwana continent at this epoch, and of the barriers to inter-oceanic relations of life which it interposed.

The Cretaceous rocks of South India include three stages in the order of superposition :

Ariyalur,
Trichinopoly,
Utatur

Utatur stage

The lowest Utatur stage rests upon an ancient land-surface of the Archaean gneisses It is mostly an argillaceous group about 1000 feet in thickness At the base it contains as its principal member a coral limestone (an old coral reef) succeeded by fine silts, clays, and gritty sandstones. The Utatur outcrop is the westernmost, and is continuous through the whole Cretaceous area along its western border. At places its width is greatly reduced by the overlapping of the next stage, the Trichinopoly. The Utatur fossils are all, or mostly, littoral organisms, such as wood-boring molluscs, fragments of cycadaceous wood, and numerous ammonites The preponderance of the latter at particular horizons enables the series to be minutely sub-divided into sub-stages and zones. The genus *Schloenbachia* occurs largely at the base, and gives its name to the lowest sub-division of the Utaturs, followed by the *Acanthoceras* zone, etc

Trichinopoly stage.

The next group is distinguished as the Trichinopoly stage, and comes somewhat unconformably on the last. This group is also 1000 feet in thickness, but in lateral extent is confined to the outcrop in the vicinity of Trichinopoly only. Both the composition of this group, as well as the manner of its

stratification, show it to be a littoral deposit from top to bottom. The rocks are conspicuously false-bedded coarse grits and sands, clays and shelly limestones, with shingle and gravel beds. Granite or gneiss pebbles are abundantly dispersed throughout the deposits The proximity of the coasts is further evidenced by the large pieces of cycad wood, sometimes entire trunks of trees, enclosed in the coarser sandstone and grits. The shell-limestone has compacted into a beautiful hard fine-grained, translucent stone which is much prized as an ornamental stone, and used in building work under the name of Trichinopoly marble. Fossils are many, though not so numerous as in the Utatur division. They indicate a slight change in the fauna

Ariyalur stage. The Trichinopoly is conformably overlain by the Ariyalur stage, named from the town of Ariyalur in the Trichinopoly district. It consists of about one thousand feet of regularly bedded sands and argillaceous strata, with, towards the top, calcareous and concretionary beds full of fossils. The Ariyalur stage occupies by far the largest part of the Cretaceous area, the breadth of its outcrop exceeding fifteen miles. The Ariyalur fauna exceeds in richness that of the two preceding stages, the gastropods alone being represented by no less than one hundred and forty species. Besides these, cephalopods, lamellibranchs, echinoderms, worms, etc., are present in a large number of species. The uppermost beds of this stage are sharply marked off from those below and form a distinct subdivision, known as the Niniyur stage, and distinguished from the remaining on palaeontological grounds, though there is no stratigraphic break visible. The *ammonites* have disappeared from this division, and with them also many lamellibranch genera, while the proportion of gastropod species shows a marked increase The fossils of the Niniyur beds reveal a Danian affinity, and, according to Mr. Vredenburg, they are equivalent to the Cardita beaumonti beds of Sind and Baluchistan. The decline of the ammonites and the increase in the families and orders of the gastropods are a very significant index of the change of times: the Mesozoic era of the earth's history has well-nigh ended, and the third great era, the Cainozoic, about to commence.

Niniyur stage.

Fauna of the south-east Cretaceous

The following list shows the distribution of the more common genera in the three stages

Utatur Stage:

Brachiopods: *Kingena, Terebratula* (many species), *Rhynchonella* (many species)

Corals: *Trochosmilia, Stylina, Caryophyllia, Isastrea, Thamnastrea*

Gastropods: *Fusus, Patella*

Ammonites: *Schloenbachia, Acanthoceras, Hamites, Mannites, Turrilites, Nautilus neocomiansis.*

Lamellibranchs: *Exogyra, Gryphaea, Inoceramus, Tellina, Opis, Nuculana, Nucula, Arca, Aucella, Radula, Pecten, Spondylus*

Trichinopoly Stage:

Ammonites: *Placenticeras, Pachydiscus, Heteroceras*

Lamellibranchs: *Pholadomya, Modiola, Ostrea, Corbula, Mactra, Cyprina, Cytherea, Trigonia, Trigonoarca, Pinna, Cardium, Pecten*

Reptiles: *Ichthyosaurus, Megalosaurus* (Dinosaur)

Ariyalur Stage:

Ammonites: *Pachydiscus, Baculites, Sphenodiscus, Desmoceras.*

Lamellibranchs: *Cytherea, Cardium, Cardita, Lucina, Yoldia, Nucula, Axinea, Modiola, Radula, Gryphaea, Trigonoarca, Exogyra*

Gastropods: *Voluta, Cypraea, Aporrhais, Alaria, Cytherea, Pseudoliva, Cancellaria, Cerithium, Turritella, Solarium, Patella, Nerita, Nerinea, Phasianella, Rostellaria*

Reptiles. (Dinosaur), *Megalosaurus*

Corals: *Stylina, Caryophyllia, Thamnastrea, Cyclolites.*

Echinoids: *Epiaster, Cardiastar, Holaster, Catopygus, Holectypus, Salenia, Pseudodiadema.*

Crinoids · *Marsupites*, *Pentacrinus*.

Polyzoa *Discopora*, *Membranopora*, *Lunulites*, *Cellepora*, *Entalophora*

Niniyur Stage : *Nautilus danicus*, large specimens of *Nerinea* and *Nautilus* with *Orbitoloides* Many gastropods

The above list gives but an imperfect idea of the richness of the fauna and of its specific relations. All the groups of the Invertebrata are represented by a large number of genera, each genus containing sometimes ten, and even more species The mollusca are the most largely represented group, and of these the cephalopods form the most dominant part of the fauna There are one hundred and fifty species of cephalopods, including three species of *Belemnites*, twenty-two of *Nautilus*, ninety-three of the common species of *Ammonites*, and three species of *Scaphites*, two of *Hamites*, three of *Baculites*, eight of *Turrilites*, eleven of *Aniosceras*, and three of *Ptychoceras*. The gastropods and lamellibranchs number about two hundred and forty species each The next group is corals, represented by about sixty species, echinoids by forty-two species, polyzoa twenty-five and brachiopods twenty

Of Vertebrata there occur seventeen species of fishes, and two of reptiles, one of *Megalosaurus* and one of *Ichthyosaurus*, relatives of the giant reptiles of the European and American Cretaceous.

Marine Cretaceous of the Narbada Valley: Bagh Beds.

The Narbada valley Cretaceous

A number of small detached outcrops occur along the Narbada valley, extending along an east-west line from the town of Bagh in the Gwalior State, to beyond Baroda, stretching as far west as Wadhwan in Kathiawar In most cases they occur around inliers of older rocks in the Deccan Trap, by the denudation of which these beds are laid bare. They are the much worn relics of another of the incursions of the sea (this time it is the sea to the north—the Tethys) during the Cenomanian transgression and, therefore, of the same age as the Utatur beds described above. The fossiliferous portion of the Bagh Cretaceous comprises only a very small thickness,

60–70 feet of limestone and marls, which are classified into three sections .

	Deccan Traps.	Danian.
Bagh beds	*Coralline limestones*. red polyzoon limestone *Deola marls*: 10 feet fossiliferous marls *Nodular limestone* (argillaceous limestone) underlain by unfossiliferous sandstone and conglomerates (Nimar sandstone).	Cenomanian.
Unconformity.		
	Gneisses : Middle Gondwana rocks, etc.	?

The lower beds are nodular argillaceous limestones, of a wide extension horizontally, met with in the majority of the outcrops between Bagh and Baroda, followed by richly fossiliferous marls—the Deola and Chirakhan marls—and by a coralline limestone formed of the remains of polyzoa The last two zones do not extend much westwards. The fossils are numerous, the chief genera being . *Ostrea, Inoceramus, Pecten, Pinna, Cardium*, (Echinoids) *Salenia, Cidaris, Echinobrissus, Hemiaster*; (Polyzoa) *Escharina, Eschara*; (Coral) *Thamnastrea*; (Gastropods) *Triton, Turritella, Natica, Cerithium*

The unfossiliferous sandstones underlying the Bagh beds of the western inliers, particularly near Baroda, have furnished to this region large quantities of an excellent building stone of very handsome appearance and great durability [1] The stone (known locally as Songir sandstone [2]) has been largely quarried in former years, and besides supplying building stones it affords good millstones.

Conclusions from the Bagh fauna

The main interest of the Bagh fauna is the contrast which it offers to the fauna of the Trichinopoly Cretaceous, from which it differs as widely as it is possible for two formations of the same age to differ. The Bagh fauna, as a whole, bears much closer affinities to the European Cretaceous than the former This is a very significant fact, and denotes a complete

[1] The appearance of the stone is greatly improved by the abundant diagonal bedding, made conspicuous by the inclusion of red and purple laminae in the white or cream-coloured general mass of the rock.

[2] The Songir sandstone of Gujarat is probably the same as the Ahmednagar sandstone of the Idar State.

isolation of the two seas in which they were deposited by an intervening land-barrier of great width, which prevented the inter-sea migrations of the animals inhabiting the two seas The one was a distant colony of the far European sea, connected through the Tethys, the other was a branch of the main Southern Ocean The two areas, though so adjacent to each other, were in fact two distinct marine zoological provinces, each having its own population. This barrier was no other than the Gondwana continent, which interposed its entire width between the two seas, viz that which occupied the Narbada valley and that which covered the south-east coast.

While the difference between these two Cretaceous provinces is of such a pronounced nature, it is interesting to note that there exists a very close agreement, both lithological as well as faunal, between the Trichinopoly Cretaceous and the Assam Cretaceous described in the last chapter. This agreement extends much further, and both these outcrops show close relations to the Cretaceous of Central and South Africa These facts clearly point to the inference that it was the same sea which covered parts of Africa, the Coromandel coast and Assam, in which the conditions of life were similar and in which the free intercourse and migrations of species were unimpeded. These series of beds must therefore show very wide faunal discrepancies from the deposits that were laid down in an arm of the great northern sea, Tethys, which was continuous from West Europe to China, and was peopled by species belonging to a different marine zoological province.

Lameta Series: Infra-Trappean Beds.

Lameta series is the name given to a fairly widely distributed series of estuarine or fluviatile deposits slightly newer in stratigraphic position than the Bagh beds of the Narbada. Outcrops of the series are found scattered in Central India, the Central Provinces, and in many parts of the Deccan, underlying directly the Deccan Traps. They generally appear as thin narrow discontinuous bands round the borders of the trap country, particularly the north-east and east borders. The name is derived from the Lameta ghat near Jabalpur,

where they were first noticed The Lameta group is not of any great vertical extent in comparison to its wide horizontality The constituent rocks of the series are cherty or siliceous limestones, earthy sandstones, grits and clays attaining in all from 20 to 100 feet in total thickness. The limestones form the most characteristic part of the series, and in some parts are of interest as offering an instructive mode of rock-genesis. These limestones, formerly regarded as of ordinary sedimentary origin, have now been found, *e.g* at Chhindwara and at some other localities to have largely originated by the chemical replacement of a former series of igneous and metamorphic rocks. Recent investigations by Dr. Fermor have revealed that many of these limestones are metasomatic in origin, and have resulted from the calcification of the underlying Archaean gneisses and schists through the process of molecular transformation, effected by the agency of percolating waters. The metasomatic changes are seen in all stages of progress, from unaltered gneisses through partly calcified rock to the typical siliceous limestone of the Lameta series. The calcification and silicification have affected all kinds of underlying rocks, gneisses, granites and hornblende and other schists. There are, however, beds of true sedimentary or organic origin as well, *e.g.* at Jubbulpore and Lameta Ghat,[1] as is evident from the few badly preserved fossil shells and other organic remains preserved in them. The sandstones and clay beds of the Lameta series have yielded a few land or fresh-water shells and the remains of some reptiles ; among the former are species of *Physa*, *Melania*, *Corbicula*, *Paludina*, etc., which are readily recognised as fresh-water, or at the most estuarine, species. The vertebrate fossils include the remains of the Dinosaurian reptiles—*Titanosaurus* and *Megalosaurus*, with *Coprolitic* relics, and the turtle (*Chelonia*) and some fish remains. The latter are valuable as having yielded conclusive evidence with regard to the stratigraphy of the Lameta series. The fishes were obtained from Donargaon in Central Provinces. They include species of *Eoserranus*, *Lepidosteus*, and *Pycnodus*. The first of these belong to the order *Teleostea* of bony fishes, the latter belong to the less highly organised order of *Ganoidea*.

Metasomatic limestones.

Age of the Lameta series.

[1] Dr C A. Matley, *Rec. G.S I.* vol. liii. pt. 2, pp. 142-169.

Dr. Smith Woodward has, from the evidence of these fish remains, determined the age of the Lameta series to be between Danian and Lower Eocene

The Lameta series everywhere rests with a great unconformity over the older rocks, whether they are Archaean gneisses or some member of the Gondwana, or on the Bagh beds. As a rule they are conformably overlain by the earliest lava-flows of the Deccan Traps series of volcanic eruptions which began at this point, and the geology of which now claims our attention. At a few places, however, the lowest Traps exhibit discordant relations to the Lametas, denoting that a considerable interval of time elapsed before the volcanic cycle began It is quite probable, however, that the discordant relations may be only apparent and may be due to the fact that in these particular cases the supposed Lameta limestone is only the altered calc-gneiss [1] which Fermor and others have found so commonly between the Traps and the Archaeans and which has in the past been so often mistaken for Lameta limestone

[1] See Chapter III p. 53 *ant*

CHAPTER XVI

DECCAN TRAP

The great volcanic formation of India

TOWARDS the close of the Cretaceous, subsequent to the deposition of the Bagh and the Lameta beds, a large part of the Peninsula was affected by a stupendous outburst of volcanic energy, resulting in the eruption of a thick series of lava and associated pyroclastic materials This series of eruptions proceeded from fissures and cracks in the surface of the earth from which highly liquid lavas welled out intermittently, till a thickness of some thousands of feet of horizontally bedded sheets of basalts had resulted, obliterating all the previously existing topography of the country and converting it into an immense volcanic plateau. That the eruptions took place from fissures such as those which arise when the surface of the earth is in a state of tension, and not from the more localised vents of volcanic craters, is evident from a number of circumstances, of which the entire absence of any traces, even the most vestigial, of volcanoes of the usual cone-and-crater type, and the almost perfect horizontality of the lava-sheets, in the immense basaltic region, are the most significant

This great volcanic formation is known in Indian geology under the name of the Deccan Traps. The term "trap" is a vague, general term, which denotes many igneous rocks of widely different nature, but here it is used not in this sense but as a Swedish word meaning "stairs" or "steps," in allusion to the usual step-like aspect of the weathered hills of basalts which are so common a feature in the scenery of the Deccan.

Area

The Deccan Traps encompass to-day an area of 200,000 square miles, covering a large part of Cutch, Kathiawar, Gujarat, Deccan, Central India, Central Provinces, etc., but

their present distribution is no measure of their past extension, since denudation has been at work for ages, cutting through the basalts and detaching a number of outliers, separated from the main area by wide distances These outliers, which are scattered over the whole ground from W. Sind to Rajahmundri on the East Coast, therefore, must testify to the
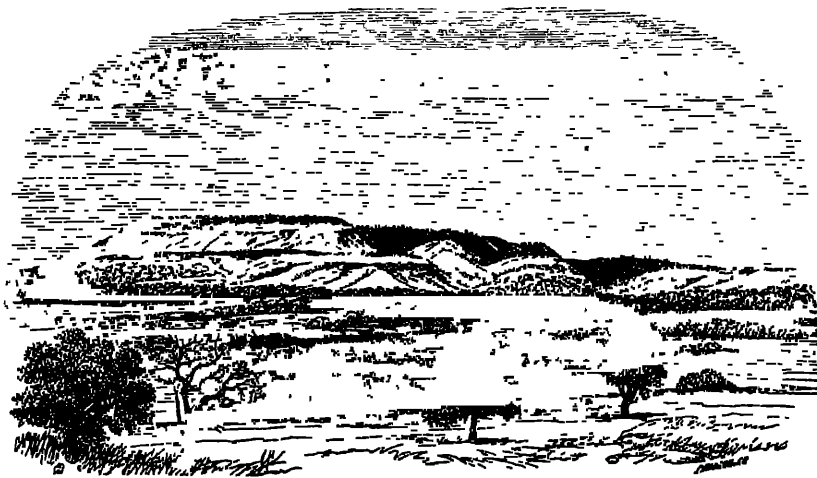
FIG 25 —View of Deccan Trap country (Oldham).

original extent of the formation, which at the time of its completion could not have been much less than half a million square miles.

Thickness.

The maximum thickness of the Deccan Traps reaches to nearly 10,000 feet along the coast of Bombay, but it rapidly becomes less farther east, and varies much at different places Towards its southern limit it is between 2000 and 2500 feet; at Amarkantak, the eastern limit, the thickness is 500 feet, while in Sind, *i.e.* the northern limit, it dwindles down to a band of only 100 or 200 feet. In Cutch the Traps are about 2500 feet in thickness. The individual lava-flows are about 15 feet on an average, but occasionally some flows are seen reaching 50 feet in thickness. The successive sheets of lava are often separated by thinner partings of ashes, scoriae and green earth, and in very many cases by true sedimentary

beds, which are hence called inter-trappean beds The ash and tuff beds are pretty uniformly distributed throughout, but they are scarcer towards the lower part.

The presence of volcanic ashes and tuffs suggests explosive action of some intensity This might have been the case at certain local vents along the main fissures, where a few subsidiary cones may have been raised. The eruption of the main mass of the lava was, however, of a quiet, non-explosive kind, as is the case with fissure-eruptions

Horizontality of the lavas

A very remarkable character of the lavas of the Deccan Trap, having an important bearing on the question of their mode of origin, is their persistent horizontality throughout their wide area It is only in the neighbourhood of Bombay that a marked departure from horizontality appears and a gentle dip is perceptible, of about 5°, towards the sea. Other localities, where a slight but appreciable inclination and even gentle folding of the lava-sheets is noticeable, are the Western Satpuras, Kandesh and the Rajpipla hills, near Broach, but these dips are believed to be due to the effects of late disturbances of level due to tectonic causes rather than to an original inclination of the flows [1]

Petrology.

In petrological composition the Deccan basalts are singularly uniform. The most common rock is a normal augite-basalt, of mean specific gravity 2 82 This rock persists, quite undifferentiated in composition, from one extremity of the trap area to the other The only variation is in the colour and texture of the rock, the most prevalent colour is a greyish-green tint, but a perfectly black colour or lighter shades are not uncommon. A few, especially those of trachytic or more acid composition, are even of a rich brown or buff colour; less common are red and purple tints. The texture varies from a homogenous crypto-crystalline, almost vitreous *anamesite*, through all gradations of coarseness, to a coarsely crystalline *dolerite*. The rock is often vesicular and scoriaceous, the amygdaloidal cavities being filled up by numerous secondary minerals like calcite, quartz, and zeolites. Porphyritic close-grained varieties, with phenocrysts of glassy felspar (sanidine) have an almost semi-vitreous lustre, a dark lustrous colour,

[1] *Rec G S I.* vol. xlvii. pt. 2, 1916.

and conchoidal fracture Owing to the high basicity, and consequent fluidity of the lavas, crystallisation was a comparatively rapid process, for which reason basalt-glass or *tachylite* is quite rare, except in some "chilled edges," where a vitreous glaze appears.

Over enormous extents of the trap area there is no evidence at all of any magmatic differentiation or variation indicated by the presence of acidic or intermediate varieties of lavas. One very notable exception, however, appears in some parts of Gujarat, *e.g.* the Pawagarh hills near Baroda, and Girnar hills of Kathiawar, where lavas of more acid or basic composition (rhyolites and gabbros) are found associated with the basalts. Their occurrence in close association with the ordinary basalts suggests that they were local differentiation products of the same magma. The most common of these acid lavas are *rhyolites*, approaching *dacites* and *quartz-andesites*, *pitchstones* and *pumice* found at Pawagarh.[1] The gabbroid complex of Girnar hills is much more noteworthy. Here are masses of gabbros and allied basic intrusives occupying a large tract of hilly country rising abruptly from the level trap-built plains of Kathiawar. The relations of the plutonic masses with one another and with the surrounding country-rocks, which are Deccan Trap flows of usual composition, suggest some post-trappean intrusion, or series of intrusions, proceeding from the same magma reservoir as that of the basalts. Subsequent differentiation of the intruded magma by prolonged segregative processes appears to have given rise to several interesting types ranging in basicity from gabbro, lamprophyre, diorite, and syenite to granophyre, which are so well exposed in the various temple-crowned hill-masses in the vicinity of Junagadh town In Kathiawar, R. B. Foote found a large number of acid and basic trap-dykes intruded into the main trap-flows. The basic varieties are of dioritic or doleritic composition, while acidic dykes are composed of trachytes or rocks of allied composition and character.

As we have seen in the last chapter, there is a much greater diversity of petrological composition among the eruptive and intrusive products of the extra-Peninsula, which are in all probability the representatives of the Deccan Trap of the Peninsula.

Microscopic character of the Deccan basalts.

In microscopical characters, the basalts are hemi-crystalline, augite-basalts, as a rule free from olivine. The mineral olivine is a very rare constituent. The bulk of the rock is composed

[1] Fermor, *Rec. G.S I.* vol. xxxiv. pt 3, 1906.

of a fine-grained mixture or ground-mass of felspar and augite Besides abundant plagioclase (labradorite or anorthite) prisms, which are often corroded at the edges, there occur sometimes large tabular crystals of clear glassy orthoclase (sanidine or adularia) as phenocrysts in the ground-mass. But porphyritic structure is not common. In the ordinary grey or green basalts there is very little glass, or isotropic residue, left, it being all devitrified; but in the black dense specimens there is a large quantity of glass present, of a green or brown colour. In some cases the peculiar amorphous isotropic product *palagonite*[1] is seen infilling the interstices of the rock The augite, the next important constituent, is present in small grains, very rarely with any crystalline outline. Magnetite is abundantly disseminated through the ground-mass either as idiomorphic crystals or grains, or as secondary dendritic aggregates.

The relation of the plagioclase to augite crystals, when apparent, is of a modified *ophitic* type, the latter having a tendency to partially enclose the former. Primary accessory minerals are few, like apatite, but secondary minerals, produced by the wide-spread meteoric and chemical changes that the basalt has undergone,. are many, viz. calcite, quartz, chalcedony, glauconite, prehnite, zeolites, etc , filling up the steam-cavities as well as the interstices of the rock. By the discoloration attending these changes the original black colour of the basalts is altered to a grey or greenish tint (glauconitisation). Glauconite is a very widely distributed product in the basalts of the Deccan Trap, both in the body of the rock as well as coating the amygdaloidal secretions. The basalt-tuffs are composed of the usual comminuted lava-particles, with fragments of pumice, crystals of hornblende, augite, felspar, etc. They are usually finely bedded, and have a shaly aspect.

The basalts exhibit a tendency to spheroidal weathering by the exfoliation of roughly concentric shells, hence rounded weathered masses are everywhere to be seen in the exposed outcrops, whether in the field and in stream-courses or on the sea-coasts. Prismatic jointing, or columnar structure, is also observed in the step-like series of perpendicular escarpments which the sheets of basalt so often present on the hill-side or slope. At some places beautiful symmetrical prismatic columns are to be seen; this is especially observed in some

[1] Palagonite is the name given to a peculiar green or brown amorphous alteration-product met with in basic volcanic rocks, resulting from change of its ferro-magnesian constituents as well as from residual glass Much of it is analogous to *chlorophaeite.* Its exact origin is not known with certainty.

dykes, *e g.* those of Cutch It is the tendency of this kind of jointing, giving rise to the landing-stair-like or "ghat"-like aspect to the basalt hills of the Deccan, that has given the name of the Deccan Trap to the formation.

Among the abundant secondary minerals that are found as kernels in the amygdaloidal cavities, the most common are the zeolites, stilbite, apophyltite, heulandite, scolecite, laumontite; also thomsonite and chabazite, calcite, crystalline quartz, or rock-crystal and its cryptocrystalline varieties, chalcedony, agates, carnelian, heliotrope, bloodstone, jasper, etc. Glauconite is abundant as a coating round the kernels

Stratigraphy of the Deccan Trap

The following table shows the stratigraphic relations of the Deccan Traps among themselves, and also with the overlying and underlying rocks:

Nummulitics of Surat and Broach; Eocene of Cutch, Laterite.

Unconformity.

Upper Traps, 1500 ft	Lava flows with numerous ash-beds, sedimentary inter-trappean beds of Bombay with large number of fossils, vertebrata and molluscan shells
Middle Traps, 4000 ft	Lavas and ash-beds forming the thickest part of the series No fossiliferous inter-trappean beds.
Lower Traps, 500 ft.	Lavas with few ash-beds Fossiliferous inter-trappeans numerous in the Central Provinces, Narbada, Berar, etc

Slight unconformity

Lameta or Infra-trappean Series; Bagh Beds; Jabalpur Beds and Older Rocks

Inter-trappean beds

At short intervals the lava-flows are separated by sedimentary beds of small vertical as well as horizontal extent, of lacustrine or fluviatile deposition formed on the irregularities of the surface during the eruptive intervals These sedimentary beds, known as Inter-trappean beds, are fossiliferous, and are valuable as furnishing the history of the periods of eruptive quiescence that intervened between the successive outbursts, and of the animals and plants that again and again migrated to the quiet centres. Usually they are only 3 to 10 feet in thickness, and are not more than three to four miles in lateral extent, but they are fairly regularly distributed throughout the *lower* and *upper traps*, being rarely absent for any distance in them The rocks comprising these beds are a black, cherty rock, resembling lydite, stratified volcanic

detritus, impure limestones and clays. Many plant-remains and fresh-water molluscan shells are entombed in these, together with insects, crustacea, and the relics of fishes, frogs, tortoises, etc The most common shell, which is also the most characteristic fossil of the inter-trappean beds, wherever they have been discovered, is *Physa prinsepii*—a species of fresh-water gastropod ; other fossils are *Lymnaea, Unio, Paludina, Valvata, Melania, Natica, Vicarya, Cerithium, Turritella, Pupa* the crustacea *Cypris* and the fresh-water alga *Chara,* with some other plants, silicified palm-wood, bones, scales, scutes, teeth of vertebrate animals, *e g* fish, frogs (*Rana* and *Oxyglossus*) and tortoises (*Hyaraspis, Testudo,* etc).

A type-section through a portion of the basalts will show the relations of the traps to these sedimentary intercalations as well as to the infra-trappean Lametas.

1. Bedded basalts. thick
2. Cherty beds, lydites, with *Unio, Paludina, Cypris,* etc., 5 feet.
3. Bedded basalts, very thick
4. Impure limestone, stratified tuffs, etc , with *Cypris, Physa,* and broken shells, 7 feet.
5. Bedded basalts, thick
6. Siliceous limestones with sandstone (Lametas), with a few shell fragments, 20 feet

The mode of eruption of the Deccan Trap

The lowermost trappean beds rest upon an uneven floor of older rocks, showing that the eruptions were subaerial and not subaqueous In the latter case, *i e* if the eruptions had taken place on the floor of the sea or lake, the junction-plane between the two would have been quite even, from the depositing action of water. As already alluded to, the actual mode of the eruptions was discharge through linear fissures, from which a highly liquid magma welled out and spread itself out in wide horizontal sheets. This view is abundantly borne out by the monotonous horizontality of the traps everywhere, and the absence of any cone or crater[1] of the usual type as the foci of the eruptions, whether within

[1] Here must be mentioned a few curious circular hollows in the surface of the trap-flows near Shikarpur in the Deccan. Their exact significance is not understood, but Fermor regards them as small vents in the unconsolidated lava-flows for the escape of steam and gases These are called "*craterlets.*"

the trap region, or on its periphery. The most gigantic outpourings of lavas in the past, in other parts of the world, have all taken place through fissures, viz. the great basaltic plateau of Idaho in the U.S.A., the Abyssinian plateau and the sheet-basalts of Antrim, etc. A recent analogy, though on a very much smaller scale, is furnished by the Icelandic type of eruptions, *i.e.* eruptions from a chain of craters situated along fissure-lines. (Cf. the Laki eruption of 1783.)

Fissure-dykes in the traps

For any proof of the existence of the original fissures which served as the channels of these eruptions we should look to the peripheral tracts of the Deccan Traps, as it is not easy to detect dykes and intrusions, however large, in the main mass of the lavas, unless the former differ in petrological characters from the latter, which is never the case actually. Looked at in this way, some evidence is forthcoming as to the original direction and distribution of the fissures. Dykes of large size, massive irregular intrusions, and ash-beds are observed at a number of places in the neighbourhood of the trap area around its boundary.[1] The most notable of these is the Rajpipla hill tract near Broach. In Cutch likewise there are numerous large dykes and complex ramifications of intrusive masses visible, along the edge of the trap country, among the Jurassic rocks. The trap area of Kathiawar is traversed by a large number of dykes intruded into the main mass of the lavas. They are of all sizes, and follow different directions. The dykes of Kathiawar are composed either of an acid, trachytic rock, or of a coarse-grained dark doleritic or dioritic mass. Similar fissure-dykes occur in the Narbada valley among the Gondwana rocks; they are likewise seen in the Konkan, while ash-beds are of very frequent occurrence near Poona, all these are evidences of the vicinity of an eruptive focus. It is clear that the foregoing instances of dykes, etc., are only the starting-points of the linear fissures which extended a great way into the interior.

[1] These dykes, intrusions and ash-beds must naturally abound in the vicinity of an eruptive site, and thus help to indicate the location of the fissure and its probable direction in the interior.

Age of the Deccan Traps

There is no internal evidence in the Deccan Traps with regard to their age The inter-trappean fossils do not throw much light on the age of the beds in which they are entombed To establish an accurate correlation of the great volcanic series in terms of the standard stratigraphic sequence, we must look to external evidences furnished by the underlying and overlying marine and estuarine beds. The eruptions were certainly subsequent to the Bagh beds (Cenomanian) which they overlie at some places, and to the Lameta series which they overlie at all others The upward limit of the series is fixed by the interstratification of a few flows of the traps with the *Cardita beaumonti* beds of Sind, whose horizon is fixed as Danian At one or two places on the west coast the traps are unconformably overlain by small outliers of Nummulitic beds, as at Surat and Broach Here the unconformable junction, denoting an appreciable lapse of time between the last eruptions and the submergence of the area is quite marked At Rajahmundri, on the Godavari delta, a distant outlier of the traps occurs resting on the top of a small thickness of marine Cretaceous sandstone of Ariyalur age. In the midst of the trap series in the last-named locality are found sedimentary beds of estuarine and marine deposition containing fossils such as *Turritella*, *Nautilus*, *Cerithium*, *Morgania*, *Potamides*, *Corbula*, *Hemitoma*, *Tympanotomus*, together with the highly typical *Physa prinsepii*. These fossils, however, do not lead to any definite inference, as the affinities of the species and genera are not very pronounced.

But from the preceding *external* evidences it is quite apparent that the Deccan Traps could not have been older than the Cenomanian stage of the Upper Cretaceous, or much younger than the Danian stage of the very topmost Cretaceous

If, however, Dr Woodward's inference of the age of the Lameta series is accepted, the age of the traps is somewhat younger (Lower Eocene).

With the trifling exceptions of Surat and Broach Tertiaries noted above, together with the alluvial deposits of river-valleys, by far the largest area of the traps is uncovered by any later formation. The peculiar subaerial alteration-

product, known as *laterite*, surmounts the highest flow of the traps everywhere as a cap, having been produced by a slow meteoric alteration of the basalts

Economics

The basalts are largely employed as road-metal, in public works, and also to a certain extent as a building stone in private dwellings. From their prevailing dark colour and their generally sombre aspect, however, the rock is not a favourite building material. The large kernels of chalcedony often yield beautiful agates, carnelians, etc., worked into various ornamental articles by the lapidaries, for which there was once a large market at Cambay. These are obtained from a Tertiary conglomerate, in which pebbles of chalcedony, derived from the weathering of the traps, were sealed up. The sands of some of the rivers and some parts of the sea-coast are magnetitic, and when sufficiently concentrated (as on some sea-beaches) are smelted for iron. The soil produced by the decomposition of the basalts is a rich agricultural soil, being a highly argillaceous dark loam, containing calcium and magnesium carbonates, potash, phosphates, etc Much of the well-known "cotton-soil," known as the "black-soil" or *regur* is due to the subaerial weathering of the basalts *in situ*, and a subsequent admixture of the weathered products with large quantities of *humus* and other organic matter.

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CHAPTER XVII

THE TERTIARY SYSTEMS

INTRODUCTORY

General. IN Europe the upper limit of the Cretaceous is marked by an abrupt *hiatus* between it and the overlying Eocene group of deposits. A sudden and striking change of fauna takes place in the latter system of deposits, by which not only do species and genera that were characteristic of the Mesozoic in general and of the Cretaceous in particular disappear from the latter group, but whole families and orders of animals die out, and new and more advanced types of creatures make their appearance The class of Reptiles, the pre-eminent vertebrates of the Cretaceous period, undergo a serious decline by the widespread extinction of many of the orders of the class, and Mammals begin to take precedence The earliest mammals are of a simple or generalised type of organisation, but they soon increase in complexity, and are differentiated into a large number of genera, families and orders Among the invertebrata the cephalopod class suffers the most widespread extinction of its species with the advent of the new era ; the ammonites and belemnites, which formed such conspicuous parts of the Mesozoic faunas of all parts, are swept away altogether They are now only the items of geological history like the trilobites of the Palaeozoic era. The place of the cephalopods is taken by the gastropods, which enter on the period of their maximum development

In India these changes in the history of life are as well marked as in the other parts of the world, although there is not any sharply marked stratigraphical break perceptible as in Europe.

The Tertiary era is the most important in the physical history of the whole Indian region, the Himalayas as well as the Peninsula It was during these ages that the most important surface-features of the area were acquired, and the present configuration of the country was outlined Concurrently with the end of the Cretaceous or with the beginning of the Eocene, an era of earth-movements set in which materially altered the old geography of the Indian region Two great events of geodynamics stand out prominently in these readjustments. one the breaking up of the old Gondwana continent by the submergence of large segments of it underneath the sea, the other the uplift of the geosynclinal tract of sea deposits to the north into the lofty chain of the Himalayas

Physical changes

The prodigious outburst of igneous forces towards the later part of the Cretaceous seems explicable when viewed in connection with these powerful crust-movements and deformations The close association of periods of earth-movements with phenomena of vulcanicity in the records of the past lends support to the inference that the late Cretaceous igneous activity was in some way antecedent to these earth-movements

The transfer of such masses of magmatic matter, as we have seen in the last chapters, from the inner to the outer zone of the earth's sphere could not but be accompanied by marked effects on the surface, chiefly of the nature of subsidence of crust-blocks and, secondly, wrinkles and folds of the superficial layers of the crust, and *vice versa*, the dislocations and deep corrugations and plications of the surface which marked the early part of the Tertiary must have produced material effects on the deeper zone The exact nature of this interaction between the exterior and interior of the earth is not understood, but there is no doubt regarding the collateral and consequential nature of the two phenomena of eruptivity and earth-movements.

The elevation of the Himalayas

The vast pile of marine sediments that was accumulating on the border of the Himalayas and in Tibet underneath the waters of the Tethys, since the Permian period, began to be upheaved by a slow secular rise of the ocean-bottom. During the long interval of ages from Mid-Eocene to the end of the Tertiary this upheaval continued, in several intermittent

phases, each separated by long periods of time, till on the site of the Mesozoic sea was reared the greatest and loftiest chain of mountains of the earth. The last signs of the Tethys, after its evacuation of the Tibetan area, remained in the form of a few straggling basins One of these basins occupied a large tract in Ladakh, to the north of the Zanskar range, and another in the Hundes province in Kumaon: on their floors were laid down the characteristic deposits of the age, including among them the Nummulitic limestone—that indubitable and unfailing landmark of geological history. These sedimentary basins are of high value, therefore, in fixing the date of commencement of the uplift of the Himalayas in the time-scale of geology There were three great phases of the upheaval of this mountain system. The first of these was post-Nummulitic, *i e* about middle of the Eocene, which ridged up the central axis of ancient sedimentary and crystalline rocks It was followed by another at the end of the Sirmur period (Mid-Miocene), which lifted the latter zone of sediments, converting them into the inner lesser ranges of the sub-Himalayas. The third and final phase elevated these two zones, together with the outlying zone of Siwalik deposits at their foot, into the Himalayan mountains as we now see them. This last phase was of Pliocene age, posterior to the deposition of the great thickness of the Siwaliks

Three phases of upheaval of the Himalayas

As already stated, it was in the early Tertiary, or the end of the Cretaceous, that Gondwanaland, the most prominent feature of the earth's Mesozoic geography, finally broke up, and the Peninsula of India acquired its present restricted form Incidental to this change, a profound redistribution of land and sea took place in the southern hemisphere Few geographical changes of any magnitude have occurred since these events, and the triangular outline of South India acquired then has not been altered to any material extent

Distribution of the Tertiary systems in India.

Tertiary rocks, from the Eocene upwards to the Pliocene, cover very large areas of India, but in a most unequal proportion in the the Peninsula and the extra-Peninsula. In the Peninsula a few insignificant outcrops of small lateral as well as vertical extent are exposed in the near vicinity of the west coast in Travancore, Gujarat and Kathiawar. A somewhat

larger area is covered on the east coast of these rocks, where a belt of marine coastal deposits of variable horizon, from Eocene to Miocene and Pliocene, is developed, and recognised as the *Cuddalore sandstone* A third and more connected sequence of Tertiary deposits is in Cutch, where a band of these rocks overlies the south border of the Deccan Trap

Tertiary systems of the extra-Peninsula

The Tertiary rocks of the extra-Peninsula are much more important, and occupy an enormous superficial extent of the country They are most prominently displayed in a belt running along the foot of the mountainous country on the western, northern and eastern borders of the country. The Tertiary rocks are essentially connected with these mountain ranges, and enter largely into their architecture. The geological map of India depicts an unbroken band of Tertiary development running from the southernmost limit of Sind and Baluchistan, along the whole of the west frontier of India, through the trans-Indus ranges, to the north-west Himalayas, where it attains its greatest width , from there the Tertiary band continues eastward, though with a diminished breadth of outcrop, flanking the foot of the Punjab, Kumaon, Nepal and Assam Himalayas, up to their termination at the gorge of the Brahmaputra. Thence the outcrop continues southward with an acute bend of the strike It is here that the Tertiary system attains its greatest and widest superficial extent, expanding over East Assam, Upper and Lower Burma to the extreme south of Burma

Dual facies of Tertiary deposits

In all these areas the Tertiary system exhibits a double facies of deposits—a lower marine facies and an upper fresh-water or subaerial. The exact horizon where the change from marine conditions to fresh-water takes place cannot be located with certainty at all parts, but from Sind to Burma, everywhere the Eocene is marine and the Pliocene fluviatile or even subaerial. The seas in which the early Tertiary strata were laid down were gradually driven back by an uprise of their bottom, and retreated southward from the two extremities of the extra-Peninsula, one towards the Bay of Bengal and the other towards Sind and the Rann of Cutch, giving place, in their slow regression, to gulf, estuarine and then to fluviatile conditions.

In the present chapter we shall take a brief general review of the Tertiary sequence in India as a whole, leaving the more detailed notice of these systems to the three following chapters In the Peninsula the following occurrences of the Tertiary strata are observed·

Travancore.

A small outcrop of Middle Tertiary limestone is found in the vicinity of Quilon beneath the superficial cover of laterite. A few bright-coloured sands and clays, enclosing bands of lignite with lumps of fossil resin (amber), and pyritous clays occur with the limestones The limestone strata are full of fossil gastropods, e g *Conus, Strombus, Voluta, Cerithium*, etc. A species of foraminifer, *Orbitolites*, is also present in the limestone.

A very similarly constituted outcrop of Tertiary rocks is seen at Ratnagiri, on the Malabar coast, underneath the laterite.

Gujarat.

Tertiaries of Surat and Broach.

Two small exposures of Eocene rocks, also underlying the laterite cap, are seen as inliers in the alluvial country between Surat and Broach The component rocks are thick beds of ferruginous clay, with gravel beds, sandstones, and limestones, from 500 to 1000 feet in thickness, resting with a distinct unconformity on the underlying traps These beds are well exposed at Bodhan, near Surat, on the Tapti. The gravels are wholly composed of rolled basalt-pebbles and some agates derived from the disintegration of the traps. Limestone strata are found in the lower part of the exposure, and are full of foraminifers belonging to several species of the genus *Nummulites*, and *Ostrea, Rostellaria, Natica*, etc., from the evidence of which the Gujarat Tertiaries are correlated to the Kirthar series of Sind. Above these beds comes a great thickness, 4000–5000 feet, of gravel beds and clayey and ferruginous sandstones well exposed at Ratanpur, near Broach The gravel and shingle beds are about wholly made up of large water-worn pebbles of basalt and chalcedony. The latter pebbles are extracted, by means of pits dug into the conglomerate,

for working them for agates. The age of the upper group is estimated as equivalent to the Gaj series of Sind

Kathiawar.

At the extreme east and west points of the Kathiawar Peninsula, Tertiary strata of Miocene or Pliocene age are found overlying the traps. The western outcrop is known as the Dwarka beds, and consists of soft gypsiferous clays overlain by sandy limestone containing many foraminifera The other occurrence is near Bhavnagar, a detached outlier of which crops out in the Gulf of Cambay as the island of Perim. The Perim island was a famous locality for the collection of Tertiary mammalian fossils, and has yielded in past years many perfect fossil specimens of several varieties of extinct quadrupeds The rock is a hard ossiferous conglomerate, enclosing many skulls, limb-bones, jaws, teeth, etc., of mammals like goats (*Capra*), pigs (*Sus*), *Dinotherium*, *Rhinoceros*, *Mastodon*, etc., of Middle and even Upper Tertiary affinities (Miocene to Pliocene) Many of these relics were found among the beach-shingles produced by wave-action on the conglomerate coasts.

Perim island Tertiary

[With the exception of the rather large Jurassic inlier around Dhrangadhra, a few small Cretaceous outcrops near Wadhwan, and the Tertiary development described above, by far the largest surface-extent of the Kathiawar peninsula is occupied by the basaltic traps. It is only in the peripheral parts of the province, in the immediate vicinity of the coast, that rocks of different composition are met with, composed of marine coastal accumulations of later ages. Of these the deposits known as the Porbander sandstones (Miliolite) are the most important, and will be described later.]

Cutch.

The Tertiary area of Cutch is on a larger scale than those last described. It is seen bordering the Trap and the Jurassic area of Cutch proper, in two long bands parallel with the coast. The older, inner, band abuts upon the traps directly, while the outer, newer, band runs parallel with the latter, but approaches the traps by overlapping successively the different members of the older Tertiaries. To the east

Tertiaries of Cutch.

it encroaches still further north, and comes to rest unconformably on the Jurassic beds by overlapping the traps in turn [1]

The bottom beds are argillaceous, with bituminous gypseous and pyritous shales, which by their constitution recall the Laki series of the much more perfectly studied Tertiary sequence of Sind This is succeeded by about 700 feet of impure, sandy limestones with *Nummulites*, *Alveolina*, corals, echinoderms, etc, representing the massive Nummulitic limestone of the Kirthar horizon. Above this comes a thick succession of clays, marls, and calcareous shales, crowded with fossils of gastropods, corals and echinoderms, *e.g.* *Turritella*, *Venus*, *Corbula*, *Breynia*, etc. This part of the sequence corresponds to the Gaj (Miocene) horizon of Sind It is succeeded by a large development of Upper Tertiary strata representing the Manchar series of Sind and the Siwalik of the Himalayas The greater part of the latter formation, however, is concealed under recent alluvium, blown sand, etc.

The accompanying table gives a general idea of the Tertiary system of Cutch, correlated with the European Tertiary :

Recent alluvium blown sand, etc		Pleistocene and Recent.
Ferruginous conglomerates, sandstones and clays (*Manchar of Sind*).	500 ft.	Pliocene.
Richly fossiliferous shales, clays, and marls with sandstone beds (*Gaj series*)	1200 ft.	Lower Miocene (Burdigalian).
Impure Nummulitic limestone (*Kirthar series*)	700 ft.	Upper Eocene (Bartonian) and
Bituminous and pyritous shales, etc. (*Laki series*).	200 ft.	Middle Eocene (Lutetian).
Basalts of the Deccan Trap.		Upper Cretaceous (Danian).

Rajputana.

Rocks of the Tertiary system occur in connection with the Jurassic and Cretaceous inliers of Bikaner and Jaisalmer in the desert tract of Rajputana, west of the Aravallis The characteristic Nummulitic limestone is readily

[1] Wynne's "Map of Cutch," *Mem G S I* vol. ix pt. 1, 1872; also "Geological Map of India" (1925), scale 1 in =32 miles

recognised in them by means of its *foraminifera* and other fossils. The nummulitic strata are underlain by a group of shaly beds, the shales enclosing some seams of bituminous coal and lignite. These reveal the Laki facies of Sind Tertiary. Some beds of yellow and brown earthy shale belonging to this series are quarried for the use of the material as fuller's earth (*Multani mattee*) The Palana coal-field of the Bikaner State is situated on an outcrop of this same series.

The Coromandel Coast.

Cuddalore series.

A fairly widely developed series of Tertiary fossiliferous rocks is found along the east coast, underlying the post-Tertiary or Quaternary formations and overlying the various Mesozoic coastal deposits. These formations are grouped under the general title of the *Cuddalore series,* from a town of that name Outcrops of the Cuddalore series commence as far north as Orissa and Midnapur, from whence they extend in a number of more or less disconnected inliers through the whole length of the coast to the extremity of the Peninsula A closely related formation is also met with on the west coast, extending as far north as Karikal. Throughout this extent the deposits are of irregular distribution and of variable composition A variously coloured and mottled, loose-textured sandstone is the principal component of the series. It is often ferruginous, argillaceous and gritty. It rests everywhere unconformably on the older deposits of various ages, in one instance overlying the Ariyalur stage of the Trichinopoly Cretaceous At some places it is covered by a laterite cap, at others by later alluvium. Some patches of the Cuddalore sandstones abound in fossils, principally gastropods, *e.g. Terebra, Conus, Cancellaria, Oliva, Mitra, Fusus, Buccinum, Nassa, Murex, Triton,* etc. *Ostrea* and *Foraminifera* of several species are also present. A great part of the Cuddalore sandstones is believed to be of Pliocene age, but some parts of it may be of older horizons.

A somewhat similar series of beds composed of sands, clays and lignite, capped by laterite, occurs on the Travancore coast, and is designated as the *Warkalli beds.* The Warkalli beds are regarded as of fresh-water origin.

TERTIARY SYSTEMS OF EXTRA-PENINSULAR INDIA

The Tertiary development of the extra-Peninsula is far more extensive, in which all the stages of the European Cainozoic from Eocene to Pliocene are developed on a scale of great magnitude It has again been more closely studied, and its stratigraphy as well as palaeontology form the subject of several voluminous memoirs published by the Geological Survey of India The palaeontological evidence available is quite ample for a very precise correlation of the different exposures with one another in the immense region which they cover, as well as with the stages of the standard Tertiary scale

The following are the principal localities where the system is best exposed . Sind, the Outer Himalayas, Burma, the Salt-Range and the Assam hills.

Sind.

The great series of Tertiary deposits of Sind are typically exposed in the hill-ranges, Kirthar, Laki, Bugti, Suleiman, etc., which separate Sind from Baluchistan The Tertiary sequence of Sind is, by reason of its exceptional development, taken as a type for the rest of India, for systematic purposes. The following table gives an idea of the chief elements of the sequence .

Manchhar series (10,000 ft)	Lower and upper beds, grey sandstones with conglomerates. Middle part brown and orange shales and clays, unfossiliferous. Lower Manchhar conglomerates contain teeth of *Mastodon*, *Dinotherium*, *Rhinoceros*.	Pliocene (Helvetian to Upper Pliocene).
Gaj series (1500 ft.)	Marine yellow limestones and shales, fossiliferous *Bugti beds* of Baluchistan, fresh-water, with mammalian fossils.	Lower Miocene (Burdigalian).
Nari series (6000 ft.)	Upper Nari, thick sandstones, unfossiliferous and partly of fluviatile origin. Lower Nari, fossiliferous, marine limestone.	Oligocene.

Kirthar series (3000-9000 ft.)	Massive nummulitic limestones forming all the higher ranges in Sind, richly fossiliferous.	Middle and Upper Eocene (Lutetian and Bartonian).
Laki series (500-800 ft.)	Argillaceous and calcareous shales with coal-measures. Alveolina limestone Thickness varying	Lybian
Ranikot series (2000 ft.).	Upper fossiliferous brown limestone and shales, marine.	London clay.
	Lower variegated shales and sandstones, gypseous and carbonaceous, fluviatile.	Thanetian.
	Cardita beaumonti beds	Danian.

With regard to the exact stratigraphic horizon of the divisions in the above table, as well as of those that follow, there is considerable difference of opinion among the palaeontologists of the Geological Survey of India, which is likely to remain unsettled for some time. The classification here adopted is from the writings of Vredenburg, Pilgrim, and other recent authors as best suited to the purposes of the student.

Himalayas.

Tertiary rocks enter preponderatingly into the composition of the outer, lower, ranges of the Himalayas, *i e* the ranges lying outside (south of) the central zone of crystalline and metamorphosed sedimentary rocks. In fact, the whole of the outer stratigraphic zone, which is known as the sub-Himalayan zone,[1] is almost exclusively constituted of Lower and Upper Tertiary rocks. With the single exception noted below, Tertiary rocks are absent from the ranges to the north of the sub-Himalayas. In the Punjab and Simla Himalayas, where these rocks have been best studied, they are disposed in two broad belts, an outer belt and an inner, formed respectively of the Upper Tertiary and the Lower Tertiary. These strata in all likelihood continue eastwards with much the same disposition, but greatly reduced in width of outcrop along the Kumaon, Sikkim and still eastern Himalayas, forming the outermost

[1] Chapter I —the Geological Classification of Himalayas, pp. 9, 10.

foothills of the mountains, separating them from the plains of the United Provinces and Bengal.

Punjab and Kashmir Himalayas.		Kumaon and Simla Himalayas.	
Upper Siwalik: Boulder-conglomerates, clays, sands and grit, 6000 ft	Siwalik System, 16,000 ft.	**Upper Siwalik**: Soft earths, clays and boulder-conglomerates, 6000-10,000 ft	Pliocene to Lower Pleistocene.
Middle Siwalik: Massive grey sandstone with pale or drab shales, 6000 ft.		**Middle Siwalik**. Massive sand-rock, clays and shales, fossiliferous at the base, 4000 (?) ft	Pontian.
Lower Siwalik: *Chinji*. bright red nodular shales with fewer grey sandstones, 3000 ft.			Sarmatian
Kamlial hard brown sandstones and purple shales, 1700-2000 ft.		**Lower Siwalik** (*Nahan*) grey micaceous sandstones and red shales, generally unfossiliferous, 3000-4000 ft.	Tortonian
Upper Murree: Soft, pale sandstones, coarse-grained, with purple splintery and nodular shales, 2000 (?) ft	10,000 ft		↑
Lower Murree indurated sandstones, deep red and purple-coloured splintery shales, 3000 ft		**Kasauli**. lacustrine, coarse soft, grey or green-coloured sandstones	Helvetian.
Fatehjang zone of ossiferous sandstones and pseudoconglomerates at base, 100 ft		**Dagshai** brackish-water or lagoon, bright red, purple nodular clays overlaid by fine sandstones	Burdigalian. Aquitanian (Lower Gaj).
Chharat: *Nummulite* shale, variegated shales, gypseous marls and thin-bedded limestone, 500-900 ft		**Subathu**: grey and red gypsous shales with subordinate lenticular nummulitic limestone with pisolitic limonite (laterite ?) at base.	Lutetian (Laki and Lower Kirthar). Thanetian (Ramkot).
Lower Nummulite (Hill Limestone): Massive well-bedded Nummulitic limestone, 200 ft.-1600 ft.		——————fault.	
Cardita beaumonti beds (Daman).		Pre-tertiary rocks of Middle Himalayas.	

At this place must be mentioned the rather exceptional circumstance of the occurrence of Lower Tertiary strata in localities north of the central crystalline axis of the Himalayas. Two or three such have been observed, *e g* North Kashmir (Ladakh), and the Hundes province of Kumaon. Of these the Ladakh exposure is best known In the upper Indus valley in Ladakh, to the north of the Zanskar range, there is a narrow elongated outlier composed of marine sedimentary strata, with nummulites and other fossils associated with peridotite intrusions and contemporaneously erupted lava-flows, ash-beds and agglomerates. The sedimentary part of this outlier resembles in some measure the Subathus of the outer Himalayas. This outcrop will be described somewhat more fully in Chapter XXVII No strata of younger age than these have been discovered in any part of the Northern Himalayas.

Burma.

The constituent series of the Tertiary system of Burma are referable with greater or less exactness to the corresponding divisions in Sind The lower nummulitic beds correspond to the Laki and Kirthar series of the latter area The middle part, composed of Oligocene and lower Miocene strata, is distinguished as the Pegu system, and is referred to the combined Nari and Gaj series, while the upper great thickness of fluviatile strata (known as the Irrawaddy system) corresponds, both in its lithological aspects as well as in its organic characters, to the Manchhars of Sind and the Upper Siwaliks of the sub-Himalayas.

Detailed stratigraphic work has been done of late years among the Lower Tertiaries of Burma which has greatly modified the old classification. The following table is based on the work of Cotter and Vredenburg.

The tertiary history of Burma is largely the history of the filling up of a north and south geosynclinal basin, 600 miles long and 150 miles wide—the basin of the old gulf of Pegu lying between the Arakan Yoma and the Shan Plateau—which was filled up by the deltaic deposits of the Irrawaddy gradually pushing southward into the gulf and ultimately replacing it by the present valley of the Irrawaddy. Hence a marine facies of deposits preponderates towards the south and characterises all the stages till as late as Pontian, while in the north the same stages show a terrestrial facies of deposits, it being a common feature of many of the stages that in their being traced laterally from north to south they

show a variation from fluviatile to estuarine and brackish-water, passing thence into marine further south, in which direction the gulf-conditions persisted till the beginning of Pliocene.

This tertiary basin of Burma is separated from the Palaeozoic and Mesozoic highlands of the Shan Plateau to the east by a great north and south boundary fault, whilst its relations to the great bounding range of the Arakan Yoma to the west are not yet known, the latter range being yet mostly a *terra incognita* to geologists

System	Division	Stage	Lithology and fauna	Equivalent
			Plateau gravels and red earth	Pleistocene.
		Irrawaddy series 5000 ft.	Fresh-water sandstones with abundant fossil wood, mammalian fossils.	Pontian.
PEGU SYSTEM.		Pyalo and Akauktaung, 4000 ft.	marine, coarse sandstone and shales with *Ostraca latimarginata*	Burdigalian.
		Kama stage. 2000 ft.	clays and sands containing rich molluscan fauna (*gastropoda*). It is the chief petroliferous horizon of Burma	Aquitanian.
		Singu stage · 1500 ft	mainly sandstones.	Upper Nari.
		Sitsayan or Padaung clay, 1500 ft.	shales with thick limestones containing large *Lepidocyclina*, *Heterostiginae* and *Schizaster*.	Lower Nari (Stampian).
		Shwezetaw · 3500 ft	shallow-water sandstones with coal-seams. *Batissa*, *Ampullina*	
EOCENE SYSTEM.	**Upper.**	Yaw stage 2000 ft.	shaly clays, marine, with *Nummulites*	
		Pondaung stage · 6500 ft	marine sandstones and clays passing up into fluviatile sandstones and deeply coloured clays containing the earliest mammalian fauna: *Anthracotheroids, Amynodonts, Rhinoceratoids and Titanotheres.*	Bartonian.
	Middle.	Tabyn clay · 5000 ft	green shales with thin coal-seams.	
		Tilin sandstone · 4000 ft	marine sands and sandstones with *Nummulites*.	Lutetian (Kirthar).
	Lower	Laungshe shales: 10,000 ft.	shales containing *Orbitoides* and *Gastropoda*.	Laki.
		Paunggyi conglomerate · 3000 ft.	basal unconformity conglomerates containing *Orthophragmina*.	Ranikot (Thanetian).
Unconformity.				
			Axial or Negrais series with *Cardita beaumonti*	Cretaceous.

The Salt Range

The Eocene nummulitic limestone is an extensively developed formation in the Salt-Range, along its whole length from the

Jhelum to its furthest western extremity In the eastern part of the range it is accompanied by the underlying Laki series The Middle Tertiary is absent from this area, as a consequence of which there is an unconformable junction between the nummulitic limestone and the Siwalik group. The latter is comprehensively developed, and constitutes the type for the Siwalik system of India. The abundance and wide distribution of its mammalian fauna has been the means of a very careful and detailed zoning of the system established by Dr Pilgrim. These palaeontological zones, worked out mainly in the Salt Range Siwaliks, now afford a basis for the correlation of the Siwalik deposits of other areas in India, Baluchistan and Burma.

Upper Siwalik 6000 ft	Boulder conglomerate zone conglomerates, sands and clays	Lower Pleistocene.
	Pinjor zone · pebbly sandstones	Pliocene
	Tatrot zone · sandstones and conglomerates	
Middle Siwalik. 6000 ft	Dhok Pathan zone · sandstones and shales, containing a rich Pontian (Pikermi) fauna	Pontian.
	Nagri zone · sandstones and pale coloured shales.	Sarmatian.
Lower Siwalik 5000 ft	Chinji series bright red nodular shales and clays with grey soft sandstones and pseudoconglomerates	Tortonian.
	Kamlial series . hard, dark-coloured sandstones and purple shales	Helvetian.
Unconformity		
500 ft. **Kirthar.**	Massive nummulitic limestone forming the plateau top, pink or cream-coloured. Few or no shales	Lutetian.
Laki. 50-100 ft	Clays, pyritous and bituminous shales containing coal-measures	Lybian.
	Cardita beaumonti beds.	Damian.

From the above resumé of the stages of Tertiary History of North India, it must have been gathered that the Tertiary Records of India are far better than the Primary and Secondary ones. It was entirely within these ages that the geomorphic evolution of India, as a separate entity, was initiated and completed, for, as we have seen in the preceding pages, in the Mesozoic Age even the skeletal outlines of this area could not be discerned. All the earth-features north of the Vindhyas came to be stamped upon it during the latter half of the Tertiary. Its physical isolation from the Asiatic Continent

was brought about by the emergence of the great mountain-barriers of the West, North, and East. Concomittantly with these was produced the extraordinary trough or rift-valley region of India—a depression 1,900 miles long and 200 miles broad in its narrower parts, separating Northern from Peninsular India—two distinct crust-segments The geological history of this vast sunken tract, now filled up by the river-deposits of the Indo-Ganges systems, does not commence till the very end of the Tertiary. Thus out of the three great geomorphic divisions of the Indian region two owe their evolution to processes operating during or subsequent to the Tertiary era of the earth's history

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CHAPTER XVIII

THE EOCENE SYSTEM

THE Eocene system includes three divisions: the lower, known as the Ranikot, directly overlies the *Cardita beaumonti* beds Its typical development is restricted to Sind, but the horizon has also been recognised in some parts of North-west India and Burma. The middle division, Laki series, is composed chiefly of variegated shales and marls, while the upper, designated the Kirthar series, includes the bulk of the Nummulitic limestone of the extra-Peninsular hill-ranges. The names of the series are derived from hill-ranges in Sind.

Ranikot Series.

Ranikot series of Sind.

This series is typically developed at Ranikot, on the Laki range, and also occupies a considerable tract in Sind. Unlike the other members of the Tertiary, the distribution of this series is limited to Sind, North-west Punjab, Hazara, Pir Panjal and Burma. The series, which lies with perfect conformity on the *Cardita beaumonti* beds, consists of soft sandstones, clays and carbonaceous and lignitic shales, containing pyrites in the lower part, succeeded by highly fossiliferous limestones and calcareous shales. The lower beds, both in their mineral composition as well as in the few dicotyledonous plants and fragmentary fossil bones that they contain, bear the impress of undoubted fluviatile origin. The overlying limestone with intercalated shales is about 700-800 feet in thickness, and abounds in fossil *echinoidea*, by means of which the series is classified into zones

Fossils of the Ranikot series.

The leading fossils of the Ranikot series are · (Echinoids) *Cidaris*, *Salenia*, *Cyphosoma*, *Dictyopleurus*, *Paralampas*, *Hemiaster*, *Schizaster*; (Corals) *Trochosmilia*, *Stylina*, *Montlivaltia*, *Feddenia*, *Isastraea*, *Astraea*, *Thamnastraea*, *Litharaea*; (Gastropods) *Rostellaria*, *Nerita*, *Terebellum*; (Foraminifers) *Nummulites* (*N planulatus* and *N. granulosa*). The species *N planulatus* is characteristic of the Ranikot horizon.

Laki Series. (**Chharat Series of N W Punjab**)

Coal-measures of the Laki series

Although of no great vertical extent, this series is of very wide geographical prevalence in India, being discernible among the Lower Tertiary outcrops of most parts, whether of the Peninsula or the extra-Peninsula It exhibits a persistent shaly facies at the base of the nummulitic limestone, with an important development of either oil or coal-measures in it in the localities of its development except the type locality, Sind, which form the source of petroleum in N.W Punjab and of all the extra-Gondwana coal produced in India The principal localities which contain a well-developed Laki series are N.W. Punjab (locally known as Chharat series), the eastern Salt-Range, Baluchistan, Jammu, Bikaner, Assam and Burma The rocks show numerous local variations at these places, but in general conform to the calcareous or gypseous shaly facies enclosing thin seams of coal The salt and gypsum of the Salt Range and Kohat according to Pascoe are deposits of this age formed during temporary drying up of some enclosed parts of the sea or lagoons. The coal-measures of the Laki series yield 400,000 tons of coal per year. The presence of pyrites in the coal renders it liable to spontaneous ignition by the oxidation of the pyrites. The pyritous shales on alteration have produced beds of alum shales as at Dundot and Kalabagh, and are a source of alum, which is manufactured at Kalabagh.

The important fossil organisms contained in the Laki strata are · *Nummulites atacicus*, *Assilina granulosa*, *Alveolina*, *Schizaster*, *Hemiaster*, *Conoclypeus*, with leaf impressions, fruits, seeds, etc , of *angiosperms*.

Kirthar Series.

Nummulitic series.

The Kirthar nummulitic limestone is one of the most conspicuous groups of rocks in many parts of extra-Peninsular India, viz Sind and Baluchistan, the Salt-Range, Hazara and North-West Frontier Provinces, and to a limited extent in the outer parts of the Himalayas, the Assam hills and Burma In its type-area, Sind, it attains a great thickness of massive homogeneous limestone, capping all the high ranges of the Sind-Baluchistan frontier There is no doubt that the nummulitic limestone of India is an eastern continuation of the same formation of Europe, a direct connection being traceable between these two regions through the nummulitic limestone formations of Baluchistan, Persia, Asia Minor,

North Africa, Turkey and Greece to the west of Europe up to the Pyrenees. It thus forms a conspicuous landmark in the stratigraphical record of the whole world.

The nummulitic limestone is a white or grey-pink or buff-coloured compact cherty limestone of very homogeneous texture, preserving the same aspect over large areas. In the Salt-Range it is one of the most important formations, and covers wide areas of these mountains. The limestone has a well-defined series of joints, owing to which it has a tendency to weather in cliffs or escarpments, having the aspect of "mural escarpments," presenting from a distance the general appearance of ruined walls or fortifications. Some of the finest cliffs of the range are produced in this manner by the action of the weathering agents The mass of the rock is nearly pure calcium carbonate, made up almost wholly of foraminiferal shells, mostly of *Nummulites,* which
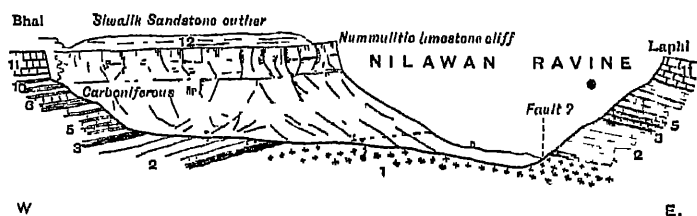
FIG. 26 —Section of nummulitic limestone (11) (in the background) (Wynne, *Mem G S I* xiv)

on weathered surfaces of the rock stand out as little ornamented discs, flat or edgewise. In microscopic sections of this rock the internal structure of the *Nummulites,* as well as other fossils, is clearly revealed, where crystallisation has not destroyed the organic structures. There are a large number of other fossils present as well, but they are difficult to extract from the unweathered rock. Large chert or flint nodules are irregularly dispersed in the limestone.

Fossils of the Kirthar series.

The fossils include many species of *Nummulites*, of which *N laevigatus*, *N. perforatus*, *N. gizehensis*, *N.* (*Assilina*) *Spira*, *N. complanatus* and *N. Murchisonia* are the most common. Other foraminifers are *Alveolina*, *Orbitoides*, *Orbitolites*, etc. Gastropods are present in large numbers, of which *Conus* *Cypraea*, *Cerithium*, *Strombus* and *Turritella* are very frequent. Portions of the corona and spines of echinoids of large size, such as *Cidaris*, *Cyphosoma*, *Echinolampas*, *Micraster*, *Hemiaster*, *Schizaster*, *Conoclypeus*, are common. The lamelli-

branchs are represented by the genera *Cytheria*, *Astarte*, *Cardita*, *Lucina*, and *Pholadomya*.

The following are the principal localities where Eocene rocks, both of the Kirthar and Laki series, are found

Kohat.

The rock-salt deposits of Kohat.

A short distance to the north of the Salt-Range at Bahadur Khel, in the hills of the Kohat district, there occurs an outcrop of Laki, Kirthar and later Tertiary rocks, which is remarkable for being underlain by an enormous mass of pure rock-salt from 500–1000 feet in thickness. At Bahadur Khel these strata are laid bare in a perfect anticlinal section , the beds of rock-salt, which are seen at the centre of the anticline are overlain by gypsum and clay-beds, which in turn are succeeded by red clays and these by Kirthar limestones, the age of which is proved by the presence of typical species of *Nummulites*, *Alveolina* and other fossils. In lateral extent the outcrop of rock-salt is traceable for several miles The salt is chemically pure crystalline sodium chloride with some admixture of calcium sulphate, but with no associated salts of potassium or magnesium as in the Salt-Range deposits of the same mineral, from which also the Kohat salt differs in its prevailing dark-grey colours and in being slightly bituminous. It appears quite probable that the two deposits, in spite of these slight differences, have had a common origin, and are of the same age, and that the apparent infra-Cambrian position of the Salt-Range salt-deposits, as seen near Khewra, is due to overthrust or underthrust faulting.

Hazara.

Eocene rocks, principally composed of nummulitic limestone, play a prominent part in the geology of Hazara and, indeed, of the whole country around the N.W. frontier. At the base, the coal-bearing Ranikot series is identified, though it does not possess any economic resources, the quantity as well as the quality of coal being very inferior. The nummulitic limestone is a grey or dark-coloured massive rock of great thickness interbedded with nummulitic shale beds ; in all these respects it is sharply distinguishable from the Salt-Range rock. The nummulitic limestone passes up into the great Murree series of fluviatile deposits. The Eocene of Hazara probably extends eastwards beyond the Jhelum, following the great bend of the mountains

Outer Himalayas.

The Eocene of the Outer Himalayas is distinguished as the Subathu series, which is collateral with part of the Kirthar series, together with its underlying Laki series. The Subathus are also composed of nummulitic limestone, but the latter is quite subordinate and contains a greater proportion of interbedded shales and sandstones than is the case with the typical Kirthar limestone There is also a difference in colour and texture, the Subathu limestone being grey to black in colour, very compact and thinly bedded. At the base there is a variable development of the Laki series in some localities, but the group is very inconstant, and bears workable coal-seams only in one locality.

Subathu series.

The Subathu series is typically developed near Simla, from a military station near which the group takes its name The rocks are red and grey, gypsiferous and calcareous shales, with a subordinate formation of limestones in which *Nummulites*, with other Eocene fossils, are found. The coal-bearing Laki shales are subordinate in this area, the lower beds being instead ferruginous sandstone and grits containing pisolitic haematite and limonite

In the north-west or Kashmir Himalayas, the Subathus occur as a number of large and small inliers exposed in the crests of anticlinal folds of the outer ranges In the Jammu hills, at Riasi and near Poonch, the largest of these inliers occur The Subathu rocks are exposed round inliers of Jurassic (?) limestone protruding out of Murree strata. Among these the Laki horizon is recognised by the presence of some thin seams of coal underlying the nummulitic limestone. The pisolitic iron ore of Subathu occurs at the base and has concentrated into an ironstone, workable as an ore of iron. Also associated with the basal beds at both these localities there occurs an extensive deposit of bauxite. Its occurrence near the base of the Eocene, indicating a great regional unconformity, is suggestive of a lateritic origin.

Assam.

Eocene rocks are well developed in the Assam hills, the Garo, Khasi and Jaintia ranges, wherein both the Kirthar and Laki stages are contained. These rocks occur in a long narrow belt underneath a more massive development of younger Tertiary strata. They overlie conformably the underlying Cretaceous. The Lower Tertiary deposits of Assam are full of economic resources, being the carriers of

Economic utility of Assam Eocene rocks.

several valuable coal-measures, with some of which is associated a group of petroliferous strata, containing large stores of mineral oil. The nummulitic limestone, again, is an excellent building and road-making material, also furnishing large quantities for burning.

In the Garo hills the Eocene beds lie conformably over the Cretaceous, and consist principally of shaly nummulitic limestone, clays and argillaceous sandstones. The fossils are allied to the other Eocene strata already considered

In the Khasi hills the nummulitic limestone with interbedded sandstones is a prominent formation, attaining a thickness of nearly 1000 feet. The town of Cherrapunji stands upon these rocks. Coal occurs in thick seams among the sandstones and shales, with fire-clays and clay-ironstones. The most common fossils are . *Nummulites, Operculina, Ostrea, Pecten, Cardium, Natica, Cerithium, Turritella.*

But the strata which contain the most promising coal-measures of Assam are those which are developed in the north-east, in the hills north of the Brahmaputra, in the Sibsagar and Dibrugarh districts The Makum field, which has the largest output of coal, belongs to this group. Associated with the coal-bearing series there also occurs an important oil-bearing horizon which supports the oil-field of Digboi, the principal oil-centre of Assam. It is believed that these coal- and oil-bearing series of strata are of somewhat younger age than the Khasi series. From the analogy of the chief petroleum-bearing horizon of Burma, which is Miocene, the Assam series is also believed to be of that age

Underlying the Tertiary coal-measures of N.E. Assam, and post-nummulitic in age, is a group of shales and sandstones, known as the *Disang Series*, from the Disang river. A similar group of rocks is met with in the Mikir hills farther west.

Burma.

Eocene rocks of Burma are developed on a large scale, reaching an aggregate thickness of over 20,000 ft. They comprise a totally different (coastal) facies of deposits than that of their homotaxial representatives in India. Cotter has divided them into six stages (*vide* table on page 213) The tertiary sequence commences with a true basal conglomerate, of Ranikot age, resting over a somewhat obscure group of altered Cretaceous sandstones and shales, which form the core of the Arakan Yoma from Cape Negrais to as far north as the Assam Ranges, known as the Negrais series or Axial

series. The Laki horizon is coal-less, though thin seams of coal have been met with at a higher horizon (Tabyn clays). The Upper Eocene of Burma is of great interest, the Nummulitic sea was temporarily thrown back by thick deltaic accumulations, in which are preserved the earliest fossil mammals of the Indian region. Marine conditions were soon resumed, however, before the Eocene period came to a close

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CHAPTER XIX

THE OLIGOCENE AND LOWER MIOCENE SYSTEMS

Nari and Gaj series Mekran system Pegu system.

FORMATIONS corresponding in age to the Oligocene and Lower Miocene are developed in Sind and Baluchistan—exhibiting a two-fold facies of deposits—one arenaceous, an enormous thickness of shallow-water sandstone and arenaceous shales, with only a subordinate formation of limestone; the other calcareous, composed of limestones and calcareous shales. The former type, closely resembling the Flysch of Switzerland, prevails in Baluchistan, covering a wide tract on the Mekran coast. This formation is designated the Kojak shales. The latter facies prevails in Sind, where the calcareous element is more prevalent with large assemblages of well-preserved fossils. Two divisions are distinguished in these, the lower part constituting the Nari series and the upper the Gaj series. In Burma Middle Tertiary rocks of analogous horizon, but of a different lithological composition, are known as the Pegu system, whereas in the Outer Himalayas they constitute the great part of the Sirmur system (Eocene and Lower Miocene) the lower members of which belonging to the Eocene have already been described under the title of the Subathu series. In the Punjab and Kohat area the Nari series is believed to be absent, together perhaps with the upper part of the Kirthar. Here a palaeontological break is noticed between the Chharat series and the base of the Murrees, the *Fatehjang zone* of which, according to Pilgrim, indicates Gaj homotaxis.

Sind.

Nari series.

Leaving the less interesting, because unfossiliferous, flysch-deposits [1] known as the Kojak shales, we shall consider their equivalent formation in Sind. The lower part, forming the

[1] Consisting of green shales and sandstones with a few Oligocene fossils.

Nari series, conformably overlies the Kirthar limestone. The name is derived from the Nari river, along the banks of which a section of the series is seen The lower part of the Nari is composed of limestone and calcareous rocks, but they give place to finely-bedded sandstones and shales in the upper part. At the top the group consists of coarse deposits, massive sandstones and conglomerates The shaly partings among the sandstones contain plant impressions, and are thought to be of fluviatile deposition. Among the calcareous bands of the upper part of the Nari, the foraminifers attain their highest development, manifested as much by the organisation of the specific types as by the size attained by the individuals of the species Large shells or tests of *Nummulites* of 2 to 3 inches in diameter are not uncommon. The most frequent species are · *N. intermedius*, *N. sublaevigatus*, *N. vascus*, accompanied by *Lepidocyclina*, and some other foraminifers. Other fossils are: *Montlivaltia*, *Schizaster*, *Breynia*, *Eupatagus*, *Clypeaster*, *Lucina*, *Venus*, *Arca*, *Corbula*, *Ostrea* (sp *angulata*) and *Natica*, *Voluta*, etc.

Gaj series. The Nari strata are conformably overlain by the Gaj series; the latter consist of rich fossiliferous dark-brown coral limestone, with shales, distinguished from the underlying Nari by the absence of *Nummulites*. The higher beds are red and olive shales which are sometimes gypseous; these in turn pass up into a series of clays and sandstones whose characters suggest deposition in an estuary or the broad mouth of a river This shows a regression of the sea-border and its replacement by the wide basin of an estuary. Fossils are very numerous in the marine strata, representing every kind of life inhabiting the sea The commonly occurring forms are: *Ostrea* (sp. *O multicostata* and *O. latimarginata*), *Tellina*, *Brissus*, *Breynia*, *Echinodiscus*, *Clypeaster*, *Echinolampas*, *Temnechinus*, *Eupatagus*, *Lepidocyclina* and *Orbitoides*. The species *Ostrea latimarginata* is highly characteristic of the Gaj horizon, it being met with also in the parallel group of deposits forming the upper part of the Pegu system of Burma. It is evident from the estuarine passage-beds that the Upper Gaj was the time for the expiry of the marine period in Sind and the beginning of a continental period On the continent

which emerged from the sea, a system of land deposits began to be formed, which culminated in an alluvial formation of great thickness and extent enclosing relics of the terrestrial life of the time A *Rhinoceros* is the only land-mammal whose remains have been hitherto obtained from the Upper Gaj beds.

Bugti beds.

In the Bugti hills of the Bugti country, in East Baluchistan, the fluviatile conditions had established themselves at an earlier date, the marine deposits in that country ceasing with the Nari epoch. The overlying strata, *i e* the upper part of the Gaj, are fluviatile sandstones containing a remarkable fauna of vertebrates, of Upper Oligocene or Lower Miocene affinities The leading fossils are. (Mammals) *Anthracotherium*, *Cadurcotherium*, *Diceratherium*, *Baluchitherium*, *Brachyodus*, *Teleoceras* and *Telmatodon*, together with a few fresh-water molluscs, among which are a number of species of *Unio*. These beds are known as the Bugti beds.

Himalayas.

Dagshai and Kasauli series

The Sirmur system is the name given to the Lower and Middle Tertiary (Eocene to Lower Miocene) rocks of the Outer Himalayas. We have already considered the portion comprising the Eocene in the last chapter; the remaining portion of the group includes two series. the Dagshai and Kasauli series, which conformably overlie the Subathus in the order named. Both these series are typically developed in the Simla area. The lower, Dagshai, is composed primarily of two types of rocks. The lower part, bright red nodular clay; the upper is a thickly stratified, fine-grained, hard sandstone which passes up, with a perfect transition, into the overlying Kasauli group of sandstones, which rocks are the chief components of the Kasauli series. No fossils are observed in the Dagshai group except *fucoid* marks and worm-tracks, fossils which are of no use for determining either the age of the deposit or its mode of origin The Kasauli group also has yielded no fossils except a few isolated plant remains and a *Unionid* The only traces of life visible in this thick monotonous pile of grey or dull-green coloured, coarse, soft sandstones are referred to a palm, *Sabal major*, some impressions of the leaves of which are seen on the laminae This individual fossil is, however, of importance because of its

enabling the Kasauli horizon to be recognised in the north-west, beyond the Ravi, in the Jammu hills and farther west, where a parallel series of fluviatile deposits extends in a broad outcrop in continuation of the same strike.

Murree series

In the outer hills fringing the Jammu and Kashmir Himalayas and the area to the west, i e, beyond Hazara, the combined Dagshai and Kasauli horizons are represented by a thick group of red and purple sandstones and shales to which the name Murree series is given. The outcrop of the Murree group is very broad in the Hazara district and in the Murree hills, but it considerably narrows further east. Near Chamba it merges into the typical Dagshai-Kasauli band of the Simla area, a connection between the two being discernible in some plant-bearing beds in the valley of the Ravi.

The Murree series comes conformably over the Subathu limestones and shales, inliers of which are seen to crop out at various places, from amidst truncated isoclinal folds of the former. The strata are red and purple shales veined by calcite, with grey and purple, false-bedded sandstones, and concretionary clay pseudoconglomerates. The whole thickness is unfossiliferous in the main, but for a few impressions of the leaves of *Sabal major* and some other obscure leaves and tissue of plants with rarely some *Unionid* shells. A few ossiferous beds are seen at the base of the series, distinguished as the *Fatehjang beds*, the organic contents of which indicate a stratigraphic position akin to the Bugti beds of Baluchistan.

Fatehjang beds.

The above description applies more appropriately to the lower part of the Murrees; the Upper Murrees, which have lately been distinguished in Rawalpindi and Poonch areas, form a distinct group, being composed of softer, coarser and paler sandstones bearing frequent impressions of *dicotyledon* leaves; petrified wood is not common in the sandstones. The shales are less in volume but are indistinguishable from typical Lower Murree shales Structurally the Upper Murrees are distinguished by their freedom from compression and the tight isoclinal system of folding, so usually seen in the Lower Murrees, being generally found in open broad synclinal basins among the latter. The Upper Murrees may be regarded as beds of passage between the true Murrees and Siwaliks.

No Oligocene or Lower Miocene strata were deposited in the Salt-Range, where, in consequence, there occurs a gap represented by an unconformable junction between the Kirthar and the overlying Upper Tertiary Siwalik system of beds.

Assam.

The coal-measures of the Assam hills, described in the last chapter, are conformably overlain by younger strata representative of the Nari and Gaj horizons of Sind. They are composed of sandstones principally, the lower beds of which have yielded many gastropod shells, including *Conus*, *Dolium*, and *Dentalium*, with *Leda*, *Nucula*, *Tellina*, etc.

The Tipam and Dihing series.

Still younger Tertiary rocks than these are met with in Upper Assam in the north-east, and are described as the Tipam and Dihing series. The former is a thick sandstone-formation overlying the coal-measures of north-eastern districts of Assam. It is succeeded by a group of still newer conglomerates, the Dihing series. Both these groups are, however, regarded from their position as well as by their characters and relations to be the equivalents of the Siwalik system of the Himalayas, or the Irrawaddy system (Fossil-wood group) of Upper Burma, which latter they resemble in enclosing large fragments of petrified wood

Burma

The Pegu system.

Middle Tertiary rocks occupy a large area in Burma, which has been surveyed in considerable detail of late years, and divided into six stages. The formations are grouped together and named the Pegu system, which covers a large tract in the Irrawaddy basin, and extends a considerable distance to the north, in which direction the various marine stages of the Pegus pass laterally into deposits of fresh-water type. The Pegu system of Burma has received much attention from geologists and prospectors because of its containing a succession of several rich molluscan faunas and because of its enclosing petroliferous sands and clays which yield all the petroleum of Burma. The system is divided into four sections, which aggregate in all about 12,000 feet. The whole group is marine in south Burma.

Fossils.

The Kama stage, the richest fossil-bearing horizon of the Pegu system, has yielded a varied molluscan fauna of Gaj or Aquitanian age The leading genera of fossils are : (Lamellibranchs) *Ostrea, Lima, Mytilus, Modiola, Pinna, Arca, Cyrena, Cytheria, Dione, Tapes, Dosinia, Venus, Tellina, Solen, Pholas,* etc ; (Gastropods) *Trochus, Solarium, Turritella, Natica, Rimella, Trivia, Triton, Fusus, Voluta, Ancillaria, Conus,* etc. ; (Echinoids) *Cidaris* and *Clypeaster*, (Coral) *Flabellum*

The Kama clays.

The Kama clays, the uppermost of the divisions of the Pegu system, form economically one of the most productive horizons in the geology of Burma It is the main oil-bearing formation of Burma which has yielded, since 1890, large quantities of petroleum and its associated products. The oil-springs and wells have in recent years produced some 270,000,000 gallons of oil per year. The outcrop of the Kama clays extends along the Irrawaddy basin, a considerable distance northwards, and supports the famous oil-fields of Yenangyaung, Singu, Yenangyat, Minbu, together with a number of smaller fields. Wherever the Kama clays outcrop in a denuded anticlinal arch, artificial borings are sunk for obtaining oil.

Petroleum.

[Petroleum is a liquid hydrocarbon of complex chemical composition, of varying colour and specific gravity (0 8–0 98) Crude petroleum consists of a mixture of hydrocarbons—solid,[1] liquid and gaseous—which are all very much alike in their nature. Petroleum deposits are rarely free from gases—called *Natural gas* —while solid hydrocarbons are also commonly present.

Origin of petroleum Igneous theory

The *origin* of petroleum is not quite satisfactorily settled. Various theories have been advanced, but only two of them find general acceptance. The first of these ascribes an *igneous* origin to the oil, and the other an *organic* mode of origin The igneous hypothesis explains the origin of the hydrocarbons by the action of steam on the metallic (generally iron) carbides which are supposed to exist in large quantities in the interior of the earth. The hydrocarbons resulting from this action are forced up by the expansion of the steam or heated water Petroleum has been formed synthetically by this process in the laboratories of chemists.

[1] The impure bituminous substance sold in the bazaars as a drug of many virtues (Salajit) is a solid hydrocarbon found in some parts of the Himalayas as a superficial deposit This substance, however, has nothing in common with petroleum, being of entirely different, and recent, origin

But this view of its origin in nature is not in accord with geological facts, as petroleum is more often found associated with the younger sedimentary rocks—often of Tertiary age—than with the older, more deep-seated, crystalline rocks with which, if this supposition be true, the hydrocarbons must occur more usually. In actual cases they are very rare in such deposits.

The organic theory. The organic theory regards the petroleum as derived from animal and vegetable tissues under certain circumstances Many sedimentary strata contain crowds of organisms entombed in them at the time of their deposition, and these are transformed, in course of time, into natural hydrocarbons, by a process of slow destructive distillation, when it takes place at low temperature, and under water, excluded from contact with the air It is considered probable that the vital action of *bacteria* is a factor in these processes, especially in the elimination of the nitrogen of animal tissues. The exact series of changes undergone is not known, but this view is more generally held than the former, and it appears to be more in accord with observed geological facts, as will be seen from what follows

Mode of occurrence Petroleum is generally found in sand-beds and sandstones intercalated between clays and shales It is rarely found without gas, and saline water is likewise often present, associated with the oil If the containing strata are horizontal, the oil and gas are generally irregularly distributed, but in inclined and folded strata they are found collected in a sort of natural chamber or reservoir, in the highest possible situations, *e g* the crests of anticlines. In such positions the gas collects at the summit of the anticlines, with the oil immediately below it This follows of course from the lower density of the oil as compared with the water saturating the petroliferous beds "In all cases there must apparently be an impervious bed above to prevent an escape of the oil and gas, and in this there is a certain similarity to the conditions requisite for artesian wells, but with the difference that the artesian wells receive their supplies from above and must be closed below, while the oil and gas wells receive their supplies from below and must be closed above. Both require a porous bed as a reservoir, which in the one case, ideally, but not always actually, forms a basin concave above, in the other concave below "[1] In dry rocks, however, the oil can occur in all situations and does occur, *e g* in the bottoms of synclines.

Petroleum usually occurs saturating porous sand-beds, sandstones and conglomerates, less frequently limestones; it also occurs filling up cavities and fissures in rocks like shales These strata must be capped by impervious beds in order that the oil be not dissipated by percolation in the surrounding rocks. The petroleum, as well as the gas, usually occurs under considerable pressure and escapes with great force, rising some hundred feet above the ground, when a boring is driven through the overlying rocks.

[1] Chamberlin and Salisbury, *Geology*, vol. ii. 1909.

The oil and gas are often not indigenous to the rocks containing them, but have come from some neighbouring source by a process of capillary action and percolation, underground water helping in the migration.]

The three petroleum areas of India—Burma, Assam and N.W Punjab (which are also the areas of tertiary coal)—possess, according to Dr. Pascoe, a striking analogy, having originated by the desiccation and filling up of three gulfs or narrow arms of the Nummulitic sea by the continuous in-pushing, in each case, of a delta of a large river, which has ultimately superseded the gulf This conception has not only explained the physical conditions under which the coal and oil deposits of these regions were accumulated, but also cleared several features in the hydrography and late drainage history of north India and Burma.

Oil- and coal-forming conditions prevailed in the Punjab during Eocene and in Assam and Burma during Miocene age. It appears probable, from the occurrence and relations of the Burma and Assam coal- and oil-fields, that in all these centres oil and coal are mutually complementary products, transformed out of the same raw materials that were accumulated on the deltaic flats and subsequently entombed in the growing silts [1]

Igneous action during the Oligocene and Lower Miocene

The Middle Tertiary was the period for another series of igneous outbursts at all parts of extra-Peninsular India. The igneous action was, this time, wholly of the intrusive or plutonic phase The early Eocene rocks were pierced by large intrusive masses of granite, syenite, diorite, gabbro, etc. In the Himalayas, in Baluchistan and in Burma the records of this hypogene action are numerous and of a varied nature. Intrusions of granite took place along the central core of the Himalayas In Baluchistan the plutonic action took the form of *bathyliths* of granite, augite-syenite, diorite, porphyrites, while in Upper Burma and in the Arakan Yoma it exhibited itself in periodotitic intrusions piercing through Miocene strata Those geologists who ascribe an igneous mode of origin to petroleum, refer the petroleum deposits of the Pegu system to the same series of plutonic action as

[1] Dr Pascoe, *Mem G S I* vol xl pp 318-323

one of its varied forms of manifestation. The salt deposits of the Salt-Range and Kohat, likewise, are regarded as another phase of this very action by these geologists

In all the above Tertiary provinces of India that we have reviewed so far, from Sind to Burma, the transition from an earlier marine type of deposits to estuarine and fluviatile deposits of later ages must have been perceived. The passage from the one type of formation to the other was not simultaneous in all parts of the country, and marine conditions might have persisted in one part long after a fluviatile phase had established itself in another; but towards the middle of the Miocene period the change appears to have been complete and universal, and there was a final retreat of the sea from the whole of north India. This change from the massive marine nummulitic limestone of the Eocene age, containing abundance of foraminifera, corals and echinoids, to the river-deposits of the next succeeding age, crowded with fossil-wood and the bones of elephants and horses, deer and hippopotami, is one of the most striking physical revolutions in India. We must now turn to the great system of Upper Tertiary river-deposits which everywhere overlies the Middle Tertiary, enclosing in its rock-beds untold relics of the higher vertebrate and mammalian life of the time, comprising all the types of the most specialised mammals except Man.

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CHAPTER XX

THE SIWALIK SYSTEM

MIDDLE MIOCENE TO PLIOCENE

General.

UPPER Tertiary rocks occur on an enormous scale in the extra-Peninsula, forming the low, outermost hills of the Himalayas along its whole length from the Indus to the Brahmaputra. They are known as the Siwalik system, because of their constituting the Siwalik hills near Hardwar, where they were first known to science, and from which were obtained the first palaeontological treasures that have made the system so famous in all parts of the world The same system of rocks, with much the same mineralogical constituents and palaeontological characters, is developed in Sind and Burma, forming the bulk of their hill-ranges. At the last-named localities the system is designated by different names, *e g.* the Manchar system in Sind and the Irrawaddy system in Burma, though there is but little doubt as regards the parallelism of all these groups.

The Siwalik deposits

The composition of the Siwalik deposits shows that they are nothing else than the alluvial detritus derived from the subaerial waste of the mountains, swept down by their numerous rivers and streams and deposited at their foot. This process was very much like what the existing river-systems of the Himalayas are doing at the present day on their emerging to the plains of the Punjab and Bengal.

The only difference is that the former Siwalik alluvia have been involved in the latest Himalayan system of upheavals, by which they have been folded and elevated into their outermost foothills. This circumstance has imparted to them high dips and some degree of induration, both of

which are absent from later alluvial deposits of the plain of India

In the severe compression and stresses to which they have been subjected in the mountain-building processes, some of the folds have been inverted or *reversed*, with the overturning of the fold-planes to highly inclined positions As is often the case with reversed folds, the middle limb of the fold (which has to suffer the severest extension), having reached the limit of its strength, passed into a highly inclined fracture or *thrust-plane*, along which the disrupted part of the fold
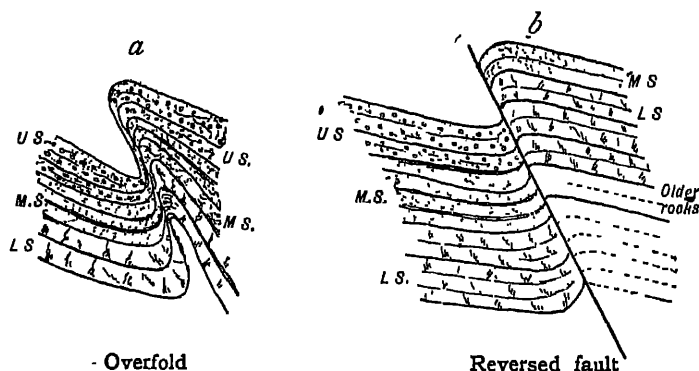
FIG 27 —Diagrams to illustrate the formation of reversed faults in the Siwalik zone of the Outer Himalayas

has slipped bodily over for long distances, thus thrusting the older pre-Siwalik rocks of the inner ranges of the mountains over the younger rocks of the outer ranges.

The geotectonic relations of the Siwaliks

This is a most signal, as it is the most characteristic, feature of the Siwaliks of the Himalayas throughout their extent. Wherever the Siwalik rocks are found in contact with the older formations, the plane of junction is always a reversed-fault, with an apparent throw of many thousand feet, and along which the normal order of superposition of the rock-groups is reversed, the younger Siwalik beds resting under the older Sirmur and dipping under them. This plane of contact is known as the *Main Boundary Fault*—a very constant feature of the structure of the Outer Himalayas along their whole length from the Punjab east of the Chenab to Assam.

The "Main Boundary" is again not the only fault, but is one of a series of more or less parallel faults among the Tertiary zone of the Outer Himalayas, all of which exhibit the same tectonic as well as stratigraphic peculiarities, i e the fault has taken place along the middle-limb of the folds and the lower and older rocks are thrust above the upper and younger, viz the Siwalik under the Sirmur, and the latter underneath the still older strata of the Middle Himalayas

The "Main Boundary" fault

The researches of Middlemiss and Medlicott in Himalayan geology have given quite a new meaning to these remarkable series of fractures. They have shown that the "Main Boundary" is not of the nature of a mere ordinary dislocation which limits the boundary of the present distribution of the Siwaliks, but it marks the *original limit of deposition* of these strata against the cliff or foot of the then existing mountains, beyond which they did not extend, could never, in fact, extend. Subsequent to their deposition this boundary has been doubtless further emphasised by some amount of faulting. The other faults are also of the same nature, and indicate the successive limits of the deposition of newer formations to the south of, and against, the advancing foot of the Himalayas during the various stages of their elevation. This view of the nature of the main boundary will be made clearer by imagining that if the rocks of the Indo-Gangetic alluvium, at present lying against the Siwalik foot-hills, were to be involved and elevated in a further, future phase of Himalayan upheaval, they would exhibit much the same relations to the Siwalik strata as the latter do to the older Tertiary or these in turn do to the still older systems of the Middle Himalayas. These reversed faults were thus "not contemporaneous but successional," each having been produced at the end of the period during which beds immediately to the south of it were deposited

The real nature of the "Main Boundary" fault

An important observation, among others, which has led these distinguished workers to the above interpretation of the nature of the "Main Boundary" fault is that nowhere do the younger Siwaliks overstep the fault, or extend in outlying patches beyond it, except very locally as would have been the case if the dislocation had originated long subsequent

to their formation. In the latter case outliers of the Siwalik ought to be seen resting on the Sirmur group beyond the northern limit of the main boundary Such is not the case in any marked degree

The palaeontological interest of the Siwalik system.

But the most notable character of the Siwalik system of deposits, and that which has invested it with the highest biological interest, is the rich collection of animals of the vertebrate sub-kingdom, and especially of the class mammalia, which it encloses, animals not far distant in age from our own times which, therefore, according to the doctrine of descent, are the immediate ancestors of most of our modern species of land mammalia. These ancient animals lived and died in the jungles which clothed the outer slopes of the mountains.
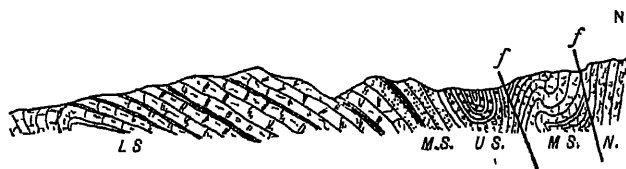
FIG 28—Section to illustrate the relations of the Outer Himalayas to the older rocks of the Mid-Himalayas (Kumaon Himalayas)
L S Lower Siwalik sandstones. *U S* Upper Siwalik conglomerate
M S Middle Siwalik sand-rock *N* Older rocks
(After C S Middlemiss)

The more durable of their remains, the hard parts of their skeletons, teeth, jaws, skulls, etc., were preserved from decay by being swept down in the streams descending from the mountains, and entombed in rapidly accumulating sediments. The fauna thus preserved discloses the great wealth of the Himalayan zoological provinces of those days, compared to which the present world looks quite impoverished Many of the genera disclose a wealth of species, now represented by scarcely a third of that number, the rest having become extinct No other mammalian race has suffered such wholesale obliteration as the Proboscideans. Of the fifteen species of elephants and elephant-like creatures that peopled the Siwalik province of India, and were indigenous to it, only one is found living to-day. The first discovered remains were obtained from the Siwalik hills near Hardwar, and the great interest which they aroused is evident from the

following popular description by Dr Mantell. "Wherever gullies or fissures expose the section of the beds, abundance of fossil bones appear, lignite and trunks of dicotyledonous trees occur, a few land and fresh-water shells of existing species are the only vestiges of mollusca that have been observed. Remains of several species of river-fish have been obtained. The remains of elephants and of mastodontoid animals comprise perfect specimens of skulls and jaws of gigantic size. The tusks of one example are 9 feet 6 inches in length and 27 inches in circumference at the base[1] This collection is invested with the highest interest not only on account of the number and variety of the specimens, but also from the extraordinary assemblage of the animals which it presents. In the sub-Himalayas we have entombed in the same rocky sepulchre bones of the most ancient extinct species of mammalia with species and genera which still inhabit India: *Eleurogale*, *Hyaenodon*, *Dinotheria*, mastodons, elephants, giraffes, hippopotami, rhinoceroses, horses, camels, antelopes, monkeys, struthious birds and crocodilian and chelonian reptiles Among these mammalian relics of the past are the skulls and bones of an animal named *Sivatherium* that requires a passing notice. This creature forms,

Fig 29 —Section across the Sub-Himalayan zone east of the Ganges river (After Middlemiss)

L.S Lower Siwalik *M.S.* Middle Siwalik *U.S.* Upper Siwalik *X* Nummulitic limestone. *T* Tal series. *N* Older rocks

[1] This has been much exceeded in some later finds, e g a specimen discovered by the writer in the upper Siwalik beds near Jammu, in which the left upper incisor of *Stegodon ganesa* was found intact with the maxillary apparatus and the upper molars The tusk measured from tip to socket 10 ft 7 in, the circumference at the proximal end being a little over 25 inches.

as it were, a link between the ruminants and the large pachyderms It was larger than a rhinoceros, had four horns, and was furnished with a proboscis, thus combining the horns of a ruminant with the characters of a pachyderm Among the reptilian remains are skulls and bones of a gigantic crocodile and of a land turtle which cannot be distinguished from those of species now living in India But the most extraordinary discovery is that of bones and portions of the carapace of a tortoise of gigantic dimensions, having a length nearly 20 feet. It has aptly been named the *Colossochelys Atlas*."

After the first few glimpses of the mammalian fauna of the Tertiary era in the Bugti beds and that in the Upper Eocene of Burma, this sudden bursting on the stage of such a varied population of herbivores, carnivores, rodents and of primates, the highest order of the mammals, must be regarded as a most remarkable instance of rapid evolution of species Many factors must have helped in the development and differentiation of this fauna ; among those favourable conditions, the abundance of food-supply by a rich angiospermous vegetation, which flourished in uncommon profusion, and the presence of suitable physical environments, under a genial climate, in a land watered by many rivers and lakes, must have been the most prominent.

Rapid evolution of Siwalik fauna

Among the Siwalik mammals there are forms, like *Proleptobos* and *Anoa*, which offer illustrations of what are called *synthetic types* (generalised or less differentiated types), *i.e.* the early primitive animals that combined in them the characters of several distinct genera which sprang out of them in the process of further evolution. They were thus the common ancestral forms of a number of these later species which in the progress of time diverged more and more from the parent type.

Lithology.

The Siwalik system is a great thickness of detrital rocks, such as coarsely-bedded sandstones, sand-rock, clays and conglomerates measuring between 15,000 and 17,000 feet in thickness. The bulk of the formation, as already stated, is very nearly alike to the materials constituting the modern alluvia of rivers, except that the former are somewhat

compacted, have undergone folding and faulting movements, and are now resting at higher levels, with high angles of dip. Although local breaks exist here and there, the whole thickness is one connected and complete sequence of deposits, from the beginning of the Middle Miocene to the close of the Siwalik epoch—Pliocene. The lower part, as a rule, consists of fine-grained micaceous sandstones, more or less consolidated, with interbedded shales of brilliant red and purple colours: silicified mono-, and dicotyledonous wood and often whole tree-trunks are abundant in the Lower Siwalik sandstones, and leaf-impressions in the shales. The upper part is more incoherent, formed of soft, thick-bedded clays and sands, capped at places, especially those at the debouchures of the chief rivers, by an extremely coarse boulder-conglomerate, consisting of large rounded boulders of siliceous rocks

The lithology of the Siwaliks suggest their origin. The upper coarse conglomerates are the alluvial fans or talus-cones at the emergence of the mountain streams; the great thickness of clays and sands represents the silts and finer sediments of the rivers, while it is probable that the lower, *e g* Kamlial beds, were formed in the lagoons or estuaries of the isolated sea-basins that were left by the retreating sea as it was driven back by the post-Sirmur upheavals. These lagoons and estuaries gradually freshened and gave rise to fluviatile and then to subaerial conditions of deposition.

The composition as well as the characters of the Siwalik strata everywhere bears evidence of their very rapid deposition by the rejuvenated Himalayan rivers, which entered on a renewed phase of activity consequent on the uplift of the mountains. There is very little of lamination to be seen in the finer deposits, the stratification of the coarser sediments is also very rude; while current-bedding is universally present. There is again little or no sorting of grains in the sandstones, which are composed of unassorted sandy detritus derived from the Himalayan gneiss, in which many of its constituent minerals can be recognised, *e.g.* quartz, felspar, micas, hornblende, tourmaline, magnetite, epidote, garnet, etc.

On palaeontological grounds the system is divisible into

Classification.

three sections, the passage of the one into the other division being, however, quite gradual and transitional

Upper Siwalik, 6000-9000 ft	Boulder-conglomerate zone. *Elephas namadicus, Equus, Camelus, Buffelus palaeindicus.*	Coarse boulder-conglomerates at the mouths of valleys, elsewhere thick earthy clays, sands, and pebbly grit, passing conformably into older alluvia.	Lower Pleisto cene.
	Pinjor zone: *E. planifrons, Hemibos, Stegodon.*		Upper Pliocene.
	Tatrot zone: *Hippohyus, Leptobos.*	Richly fossiliferous in Siwalik hills This division is predominant in E Himalayas.	Lower Pliocene.
Middle Siwalik, 6000-8000 ft.	Dhok Pathan zone: *Stegodon, Mastodon, Hippopotamus,* large *Giraffoids, Sus, Merycopotamus.*	Massive, thick, grey sandstones and sand-rock with fewer shales and clays of pale and drab colours. Pebbly at top.	Pontian (Pikermi)
	Nagri zone: *Mastodon, Hipparion, Prostegodon.*	The richest Siwalik fauna occurs in the Dhok Pathan zone of Salt-Range.	Sarmatian.
Lower Siwalik (*Nahan*), 4000 ft.-5000 ft.	Chinji stage: *Listriodon, Amphicyon, Giraffokeryx, Tetrabelodon.*	Bright red nodular shales and clays, with fewer grey sandstones and pseudoconglomerates. Unfossiliferous in the Siwalik Hills.	Tortonian.
	Kamlial stage: *Acerotherium, Telmatodon, Tetrabelodon, Anthropoids, Hyoboops*	Dark, hard sandstones and purple shales resembling Murree shales. Fossiliferous everywhere in the Punjab.	Helvetian.
Upper Murree.	Conformable passage downwards into Upper Murree sandstones and shales.		Burdigalian.

Siwalik Fauna.

The Siwalik deposits enclose a remarkably varied anc abundant vertebrate fauna in which the class *Mammalic* preponderate. The first collections were obtained from the neighbourhood of Siwalik hills in the early thirties of the las

century, in which subsequent additions were made by discoveries in the other Himalayan foot-hills It has been recently considerably enriched by discoveries in the Salt-Range, especially in its eastern extremity, by Dr. Pilgrim. He has brought to light, in a series of brilliant palaeontological researches, a number of rich mammaliferous horizons among these deposits, which are of high zoological and palaeontological interest These have established the perfect uniformity and homogeneity of the fauna over the whole Siwalik province, and have enabled a revised correlation of the system. The following is a list of the more important genera and species of *Mammalia* classified according to Dr. Pilgrim.

Upper Siwalik:

Primates · *Simia, Semnopithecus, Papio.*

Carnivores: *Hyaenarctus sivalensis, Melivora, Mustela, Canis, Vulpes, Hyaena, Viverra, Machaerodus, Felis cristata.*

Elephants: *Mastodon sivalensis, Stegodon ganesa, S clifti, S. insignis, Elephas planifrons.*

Ungulates: *Rhinoceros palaeindicus, Equus sivalensis, Sus falconeri, Hippopotamus, Camelus antiquus, Giraffa, Indratherium, Sivatherium giganteum, Cervus, Buffelus palaeindicus, Bucapra, Anoa, Bison, Bos, Hemibos, Leptobos.*

Middle Siwalik:

Primates: *Palaeopithecus, Semnopithecus, Cercopithecus, Macacus.*

Carnivores: *Hyaenarctos, Mellivorodon, Lutra, Amphicyon, Machaerodus, Felis*

Rodents: *Hystrix*

Elephants: *Prostegodon cautleyi* and *latidens, Stegodon clifti, Mastodon hasnoti.*

Ungulates. *Teleoceras, Hipparion* (very common), *Merycopotamus, Tetraconodon, Hippohyus, Sus punjabiensis, Hippopotamus irravaticus, Tragulus, Hydaspitherium, Aceratherium, Vishnutherium, Cervus simplicidens, Gazella, Tragoceras, Anoa,*

Lower Siwalik:

Primates: *Sivapithecus indicus*, *Dryopithecus*, *Palaeosimia*

Carnivores: *Dissopsalis*, *Amphicyon*, *Pallhyaena*.

Proboscidians: *Dinotherium*, *Tetrabelodon*, *Mastodon*.

Ungulates: *Aceratherium*, *Hyotherium*, *Anthracotherium*, *Dorcatherium*, *Hemimeryx*, *Giraffokeryx*, *Conohyus*, *Listriodon*, *Telmatodon*, *Brachyodus*, *Hyoboops*, *Aceratherium*, *Sanitherium*.

Besides these the lower vertebrate fossils are:

Birds: *Phalacrocorax*, *Pelecanus*, *Struthio*, *Mergus*.

Reptiles: (Crocodiles) *Crocodilus*, *Gharialis*, *Rhamphosuchus*; (Lizard) *Varanus*, (Turtles) *Colossochelys atlas*, *Bellia*, *Trionyx*, *Chitra*, *Snakes*, *Pythons*.

Fish: *Ophiocephalus*, *Chrysichthys*, *Rita*, *Arius*, etc.

A most interesting and representative collection of the Siwalik fossils of India is arranged in a special gallery, the Siwalik gallery, in the Indian Museum, Calcutta.

Age of the Siwalik system. From the evidence of the stage of evolution of the various types composing this fauna, and from their affinity to certain well-established mammaliferous horizons of Europe, which have furnished indubitable evidence of their age because of their interstratification with marine fossiliferous beds, the age of the Siwalik system is determined to extend from the Middle Miocene to the top of the Pliocene. The Dhok Pathan zone of the Mid Siwaliks is believed to be homotaxial with the well-known Pikermi series of Greece.

Parallel series of deposits. A parallel series of deposits is developed in other parts of the extra-Peninsula, as already alluded to, and is known as the *Manchar system* in Sind and the *Irrawaddy system* in Burma. They are also fluviatile or subaerially deposited sandstones, sand-rock, clays and conglomerates containing abundance of fossil-wood and mammalian remains agreeing closely with the Siwaliks.

In Burma the Irrawaddy system was formerly known as the *Fossil-wood-group*, from the extraordinary profusion of petrified wood entombed in the coarser deposits. The hundreds and thousands of whole trunks of silicified dicoty-

edon trees and huge logs lying in the sandstones suggest the lenudation of thickly forested slopes of the Arakan Yoma.

This stage rests upon the top-beds of the Pegu which are luviatile in the north and marine in the south, the exact imit being often difficult to fix. It is composed of 5000–7000 ft of coarse, current-bedded sands and sand-rock with, it the base, a conspicuous "red-bed" of lateritic origin. Two fossiliferous horizons occur in this series, separated by ibout 4000 ft. of sands The lower, containing *Hipparion* ind *Aceratherium*, denote the Dhok Pathan horizon of the Salt Range, while the upper, characterised by species of *Mastodon*, *Stegodon*, *Hippopotamus* and *Bos*, is akin to the Tatrot zone of Upper Siwaliks

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CHAPTER XXI

THE PLEISTOCENE SYSTEM

THE GLACIAL AGE IN INDIA

The Pleistocene or Glacial Age of Europe and America

THE close of the Tertiary era and the commencement of the Quaternary is marked in Europe and North America by a great refrigeration of climate, culminating in what is known as the Glacial Age. The glacial conditions prevailed so far south as 39° latitude north and countries which now experience a temperate climate then experienced the arctic cold of the polar regions, and were covered under ice-sheets radiating from the higher grounds The evidence for this great change in the climatic conditions of the globe is of the most convincing nature, and is preserved both in the *physical* records of the age, *e g.* in the characteristic glaciated topography; the "glacial drift" or moraine-deposits left by the glaciers; and the effects upon the drainage system of the countries, as well as in the *organic* records, *e g* the influence of such a great lowering of the temperature on the plants and animals then living; on the migration or extinction of species and on their present distribution

A modified Glacial Age in India.

Whether India, that is, parts lying to the south of the Himalayas, passed through a Glacial Age, is an interesting though an unsettled problem. In India, it must be understood, we cannot look for the actual existence of ice-sheets during the Pleistocene glacial epoch, because a refrigeration which can produce glacial conditions in Northern Europe and America would not, the present zonal distribution of the climate being assumed, be enough to depress the temperature of India beyond that of the present temperate zones. Hence we should not look for its evidence in moraine-débris and rock-

striations (except in the Himalayas), but in the indirect *organic* evidence of the influence of such a lowering of the temperature, and the consequent increase of humidity, on the plants and animals then living in India. Humidity or dampness of climate has been found to possess as much influence on the distribution of species in India as temperature From this point of view sufficient evidence exists of the glacial cold of the northern regions being felt in the plains of India, though to a much less extent, in times succeeding the Siwalik epoch after the Himalayan range had attained its full elevation.

The nature of the evidence for an Ice Age in the Peninsula.

This evidence, derived from some peculiarities in the fauna and flora of the hills and mountains of India and Ceylon, is thus summarised by W. T Blanford—one of the greatest workers in the field of Indian geology.

Dr Blanford's views

"On several isolated hill ranges, such as the Nilgiri, Annmale, Shivarai and other isolated plateaus in Southern India, and on the mountains of Ceylon, there is found a temperate fauna and flora which does not exist in the low plains of Southern India, but which is closely allied to the temperate fauna and flora of the Himalayas, the Assam Range, the mountains of the Malay Peninsula and Java Even on isolated peaks such as Parasnath, 4500 feet high, in Behar, and on Mount Abu in the Aravalli Range, Rajputana, several Himalayan plants exist It would take up too much space to enter into details. The occurrence of a Himalayan plant like *Rhododendron arboreum* and of a Himalayan mammal like *Martes flavigula* on both the Nilgiris and Ceylon mountains will serve as an example of a considerable number of less easily recognised species In some cases there is a closer resemblance between the temperate forms found on the Peninsular hills and those on the Assam Range than between the former and Himalayan species, but there are also connections between the Himalayan and the Peninsular regions which do not extend to the eastern hills. The most remarkable of these is the occurrence on the Nilgiri and Annmale ranges, and on some hills further south, of a species of wild goat, *Capra hylocrius*, belonging to a sub-genus (*Hemitragus*) of which the only known species, *Capra Jeemlaica*, inhabits the temperate regions of the Himalayas from Kashmir

to Bhutan. This case is remarkable because the only other wild goat found completely outside the palaearctic region is another isolated form on the mountains of Abyssinia.

"The range in elevation of the temperate flora and fauna of the Oriental regions in general appears to depend more on humidity than temperature, many of the forms which in the Indian hills are peculiar to the higher ranges being found represented by the allied species at lower elevations in the damp Malay Peninsula and Archipelago, and some of the hill forms being even found in the damp forests of the Malabar coast The animals inhabiting the Peninsula and Ceylonese hills belong for the most part to species distinct from those found in the Himalaya and Assam Ranges, etc., in some cases even genera are peculiar to the hills of Ceylon and Southern India, and one family of snakes is unrepresented elsewhere. There are, however, numerous plants and a few animals inhabiting the hills of Southern India and Ceylon which are identical with Himalayan and Assamese hill forms, but which are unknown throughout the plains of India.

"That a great portion of the temperate fauna and flora of the Southern Indian hills has inhabited the country from a much more distant epoch than the glacial period may be considered as almost certain, there being so many peculiar forms. It is possible that the species common to Ceylon, the Nilgiris and the Animale may have migrated at a time when the country was damper without the temperature being lower, but it is difficult to understand how the plains of India can have enjoyed a damper climate without either depression, which must have caused a large portion of the country to be covered by sea, a diminished temperature, which would check evaporation, or a change in the prevailing winds The depression may have taken place, but the migration of the animals and plants from the Himalayas to Ceylon would have been prevented, not aided, by the southern area being isolated by the sea, so that it might be safely inferred that the period of migration and the period of depression were not contemporaneous. A change in the prevailing winds is improbable so long as the present distribution of land and water exists, and the only remaining theory to account for

the existence of the same species of animals and plants on the Himalayas and the hills of southern India is depression of temperature "

Ice Age in the Himalayas.

When, however, we come to the Himalayas, we stand on surer ground, for the records of the glacial age there are unmistakeable in their legibility At many parts of the Himalayas there are indications of an extensive glaciation in the immediate past, and that the present glaciers, though some of them are among the largest in the world, are merely the shrunken remnants of those which flourished in the Pleistocene age. Enormous heaps of terminal moraines, now grass-covered, and in some cases tree-covered, ice-transported blocks, and the smoothed and striated, hummocky surfaces and other indications of the action of ice on land surface are observed at all parts of the Himalayas that have been explored from Sikkim to Kashmir at elevations several thousand feet below the present level of descent of the glaciers. On the Haramukh mountain in Kashmir a mass of moraine is described at an elevation of 5500 feet. On the southern slopes of the Dhauladhar range an old moraine (or what is believed to be such) is found at such an extraordinarily low altitude as 4700 feet, while in some parts of Kangra, glaciers were at one time believed, though not on good evidence, to have descended below 3000 feet level. In Southern Tibet similar evidences are numerous at the lowest situations of that elevated plateau. Equally convincing proofs of ice-action exist in the interruptions to drainage courses that were caused by glaciers in various parts of the mountains. A more detailed survey and exploration of the Himalayas than has been possible hitherto will bring to light further proofs.

The ranges of the Middle Himalayas, which support no glaciers to-day, have, in some cases, their summits and upper slopes covered with moraines. The ice-transported blocks[1] of the Potwar plains in Rawalpindi (referred to on page 266) also furnish corroborative evidence to the same effect. (Note also the testimony of some hanging valleys (p. 20), of the well-known desiccation of the Tibetan lakes (p. 22).)

[1] Middlemiss is not disposed to regard these as ice-transported *Mem.* vol xxvi 1896. See also footnote, p 267.

The extinction of the Siwalik mammals—one further evidence

Further evidence, from which an inference can be drawn of an Ice Age in the Pleistocene epoch in India, is supplied by the very striking circumstance, to which the attention of the world was first drawn by the great naturalist, Alfred Russel Wallace The sudden and widespread reduction, by extinction, of the Siwalik mammals is a most startling event for the geologist as well as the biologist The great Carnivores, the varied races of elephants belonging to no less than fifteen species, the *Sivatherium* and numerous other tribes of large and highly specialised Ungulates which found such suitable habitats in the Siwalik jungles of the Pliocene epoch are to be seen no more in an immediately succeeding age. This sudden disappearance of the highly organised mammals from the fauna of the world is attributed by the great naturalist to the effect of the intense cold of a Glacial Age. It is a well-known fact that the more highly specialised an organism is, the less fitted it is to withstand any sudden change in its physical environments; while the less differentiated and comparatively simple organisms are more hardy and survive such changes either by slowly adapting themselves to the altered surroundings or by migration to less severe environments. It is, therefore, proper to infer that the extinction of the large number of Siwalik genera and species, and the general impoverishment of the mammalian fauna of the Indian region, furnish us with an additional argument in favour of an "Ice Age" (though, of course, greatly modified and tempered in severity) in India, following the Siwaliks.

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CHAPTER XXII

THE PLEISTOCENE SYSTEM (*Continued*)

THE INDO-GANGETIC ALLUVIUM

The plains of India

THE present chapter will be devoted to the geology of the great plains of North India, the third physical division of India which separates the Peninsula from the extra-Peninsular regions. It is a noteworthy fact that these plains have not figured at all in the geological history of India till now, the beginning of its very last chapter What the physical history of this region was during the long cycle of ages, we have no means of knowing. That is because the whole expanse of these plains, from one end to the other, is formed, with unvarying monotony, of Pleistocene alluvial deposits of the rivers of the Indo-Gangetic system, which have completely shrouded the old land-surface to a depth of some thousand feet. The solid geology of the country is totally obscured underneath this mantle, which has completely buried all the past geological records of this vast tract. The deposition of this alluvium commenced after the final upheaval of the mountains and has continued all through the Pleistocene up to the present. The plains of India thus afford a signal instance of the imperfection of the geological record as preserved in the world, and of one of the many causes of that imperfection

Nature of the Indo-Gangetic depression.

In the Pleistocene period, the most dominant features of the geography of India had come into existence, and the country had then acquired almost its present form, and its leading features of topography, except that the lands in front of the newly-upheaved mountains formed a depression, which was rapidly being filled up by the waste of the highlands.

The origin of this depression, or trough, lying at the foot of the mountains, is doubtless intimately connected with the origin of the latter, though the exact nature of the connection is not known and is a matter of discussion The great geologist, Eduard Suess, has suggested, as we have already seen, that it is a "fore-deep" in front of the high crust-waves of the Himalayas as they were checked in their southward advance by the inflexible solid land-mass of the Peninsula. On this view the depression is of a synclinal nature—a *synclinorium.* From physical and geodetic considerations, Sir S Burrard, the Surveyor-General of India, has arrived at a totally novel view of the origin of the depression He considers that the Indo-Gangetic plains occupy a deep "rift-valley," a portion of the earth's surface sunk in a huge crack or fissure in the sub-crust, between parallel dislocations or faults on its two sides. The formation of this great crack, 1500 miles long, and several thousand feet deep, in the crust of the earth was, according to this view, intimately connected with the elevation of the Himalayan chain; was, in fact, according to Burrard, the prime event in the whole series of physico-geographical changes that took place at this period in the earth's history This view, which is based on geodetic observations and deduction alone, has got few geological facts in its support, and is not adopted by geologists, who conceive that the Indo-Gangetic depression is only of moderate depth, and that its conversion into the flat plains is due to the simple process of alluviation According to the latter view, these plains have been formed by the deposition of the detritus of the mountains by the numerous rivers emerging from them during a period of great gradational activity The continuous upheaving of the mountains must have rejuvenated the streams often and often, thus multiplying their carrying capacity several times their normal powers It must also be remembered that this increased stream-energy was expended on a zone of recent folding and fracturing whose disintegration must have proceeded with extreme rapidity All these were most favourable conditions for the quick accumulation of sediments in the zone of lodgment at the foot of the mountains.

Extent and thickness.

The area of these alluvial plains is 300,000 square miles, covering the largest portion of Sind, Northern Rajputana, the whole of the Punjab, the United Provinces, Behar, Bengal and half of Assam. In width they vary from a maximum of 300 miles in the western part to less than 90 miles in the eastern. The total thickness of the alluvial deposits is not ascertained, but from the few borings that have been made it appears that the thickness is more than 1300 feet below the level of the ground-surface and nearly 1000 feet below the level of the sea. All the borings that have hitherto been made, for the purpose of obtaining a supply of artesian water, have failed to reach the rocky bottom, nor have they shown any indication of an approach even to the base of the alluvium.

The highest elevation attained by the plains is 900 feet above the sea level; this is the case with the tract of country between Saharanpur, Umballa, and Ludhiana, in the Punjab. The above tract is thus the present watershed which divides the drainage of the east, *i e.* of the Ganges system, from that of the west, *i e.* the Indus and rivers of the Punjab There exist many evidences to prove that this was not the old water-parting The courses of many of the rivers of the plains have undergone great alterations. Many of the rivers are yearly bringing enormous loads of silt from the mountains, and depositing it on their beds, raise them to the level of the surrounding flat country, through which the stream flows in ever-shifting channels A comparatively trifling circumstance is able to divert a river into a newly scoured bed. The river Jumna, the sacred Saraswati of the Hindu Shastras, in Vedic times flowed to the sea, through Eastern Punjab and Rajputana, by a channel that is now occupied by an insignificant stream which loses itself in the sands of the Bikaner desert. In course of time, the Saraswati took a more and more easterly course and ultimately merged into the Ganges at Prayag. It then received the name of Jumna.[1]

[1] *Quart. Jour. Geol. Society*, xix. p 348, 1863. The above example illustrates what, in a general manner, was the behaviour of the majority of the rivers of this tract, including the Indus itself, which is supposed to have been originally confluent with the Ganges See also Pascoe, *ibid.* vol. lxxv pp 138-155 (1919), and Pilgrim, *Journ Asiat. Soc. Bengal*, vol. xv. (1919), pp 81-99

Old maps of Bengal show that hardly one hundred years ago the river Brahmaputra, which now flows to the west of Dacca, and the elevated piece of ground to its north, known as the Madhupur jungle, then flowed a great many miles to the east of these localities. This change appears to have been accomplished suddenly, in course of a few years.

Lithology.

The rocks are everywhere of fluviatile and subaerial formation—massive beds of clay, either sandy or calcareous, corresponding to the silts, mud, and sand of the modern rivers. Gravel and sand become scarcer as the distance from the hills increases At some depths from the surface there occur a few beds of compact sands and even gravelly conglomerates. A characteristic of the clayey part of the alluvial plains, particularly in the older parts of the deposits, is the abundant dissemination of impure calcareous matter in the form of irregular concretions—*Kankar*. The formation of Kankar concretions is due to the segregation of the calcareous material of the alluvial deposits into lumps or nodules somewhat like the formation of flint in limestone Some concretionary limonite occurs likewise in the clays of Bengal and Behar

Classification.

With regard to the geological classification of the alluvial deposits, no very distinctly marked stages of deposition occur, the whole being one continuous and conformable series of deposits whose accumulation is still in progress. But the following divisions are adopted for the sake of convenience, determined by the presence in them of fossils of extinct or living species of mammals :

3. **Deltaic deposits** of the Indus, the Ganges, etc. Recent.
2. **Newer alluvium :** *Khadar* of the Punjab
   Fossils, chiefly living species.
1. **Older alluvium :** *Bhangar* of the Ganges valley.
   Fossils of *Elephas antiquus*, *Equus namadicus*, *Manis gigantea*, extinct *Rhinoceros*, *Hippopotami*, etc.

Unconformity.

Rocks of Unknown Age: possibly the extension of *Archaean*, *Purana* and *Gondwanas* of the Peninsula.

The Bhangar

The *Bhangar*, or older alluvium of Bengal and the United Provinces, corresponds in age with the Pleistocene, while

the *Khadar* gradually passes into the Recent The former generally occupies the higher ground, forming small plateaus which are too elevated to be flooded by the rivers during their rise

As compared to the Bhangar, the Khadar, though newer in age, occupies a lower level than the former This, of course, happens in conformity with the principle that as a river becomes older in time, its deposits become progressively younger; and as the bed of the river is continually sinking lower, the later deposits occupy a lower position along its basin than the earlier ones Such is the case with all old river deposits (*e g* river-terraces and flood-plains) Remnants of the Bhangar land are being eroded by every change in the direction of the river channels, and are being planed down by their meandering tendencies

The Khadar. The Khadar deposits are, as a rule, confined to the vicinity of the present channels. The clays have less Kankar, and the organic remains entombed in them all belong to still living species of elephants, horses, oxen, deer, buffaloes, crocodiles, fishes, etc. The Khadar imperceptibly merges into the deltaic and other accumulations of the prehistoric times. **The Ganges delta.** The delta of the Ganges and the Brahmaputra is merely the seaward prolongation of the Khadar deposits of the respective river-valleys. It covers an area of 50,000 square miles, composed of repeated alternations of clays, sands and marls with recurring layers of peat, lignite and some forest-beds.

The Indus delta Similarly the Indus delta is a continuation of the Khadar of the Indus river. This delta is of much smaller area than the Ganges delta, since it is probable that the present delta is not of a very old age, but is of comparatively late formation It is inferred from various evidences that the Indus, within historic times, had a very much more easterly course, and discharged its waters at first into the Gulf of Cambay and then into the Rann of Cutch Both in Sind and Cutch there exist popular traditions, as well as physical evidences, to support the inference that the Indus has changed its course materially since historic times, and has deviated to a more westerly course (See p. 249)

A few other vernacular terms are employed to denote various superficial features of geological importance in this area:

Bhaber denotes a gravel talus with a somewhat steep slope fringing the outer margins of the hills everywhere. It resembles the alluvial fans or dry-deltas. The rivers in crossing them lose themselves by the abundant percolation in the loose absorbent gravels. The student will here see the analogy of this Bhaber gravel with the Upper Siwalik conglomerates. The latter was, in fact, an old *Bhaber* slope sealed up into a conglomerate by the infiltration of a cementing matrix

Terai is the densely forested and marshy zone below Bhaber. In these tracts the water of the Bhaber slopes reappears and maintains them in a permanent marshy or swampy condition.

The term *Bhur* denotes an elevated piece of land situated along the banks of the Ganges and formed of accumulated wind-blown sands, during the dry hot months of the year.

In the drier parts of the alluvial plains, a peculiar saline efflorescent product—*Reh* [1] or *Kallar*—is found covering the surface and destroying in a great measure its agricultural fertility The Reh salts are a mixture of the carbonate, sulphate and chloride of sodium together with calcium and magnesium salts derived originally from the chemical disintegration of the detritus of the mountains, dissolved by percolating waters and then carried to the surface by capillary action in the warm dry weather.

Economics. Though not possessed of any mineral resources, these alluvial plains are the highest economic asset of India because of their agricultural wealth. The clays are an unlimited store for rude earthenware and brick-making material, which is the only building-material throughout the plains, while the Kankar is of most extensive use for lime and cement-making and also for road-construction These plains are an immense reservoir of fresh sweet water, stored in the more porous, coarser strata, beneath the level of saturation, which is easily accessible by means of ordinary borings in the form of wells The few borings that have been made have given

[1] *Rec. G.S.I.* vol. xiii. pt 2, 1880.

proof of the prevalence of artesian conditions in some parts of the plains, and in a few cases artesian borings have been made with successful results

Rajputana desert

Of the same age as, or slightly newer than, the alluvial formation just described are the aeolian accumulations of the great desert tract of India, known as the Thar The Thar, or Rajputana desert, is one wide expanse of wind-blown sand stretching from the west of the Aravallis to the basin of the Indus, and from the southern confines of the Punjab plains, the basin of the Sutlej, to as far south as lat. 25°, occupying an area 400 miles long by 100 miles broad, concealing beneath it much of the solid geology of the region. The desert is not one flat level waste of sands, but there are numerous rocky projections of low elevation in various parts of it, and its surface is further diversified by the action of the prevailing winds, which have heaped up the sands in a well-marked series of ridges, dunes and hillocks. The rocky prominences which stand up above the sands belong to the older rocks of the country, presenting in their bare, bold and rounded outcrops, and in their curiously worn and sand-blasted topography, striking illustrations of the phenomena of desert-erosion The aspect presented by the sand-hills resembles that of a series of magnified wind-ripples. Their strike is generally transverse to the prevailing winds, though in a few cases, *e.g.* those occurring on the southern part of the desert, the strike is parallel to the wind-direction. In both cases the formation of the sand-ridges is due to wind-action, the longitudinal type being characteristic of parts where the force of the wind is great, the transverse type being characteristic of the more distant parts of the desert where that force has abated The windward slope is long, gentle and undulatory, while the opposite slope is more abrupt and steep. In the southern part of the desert these ridges are of much larger size, often assuming the magnitude of hills 400 to 500 feet high All the dunes are slowly progressing inland.

Composition of the desert sand

The most predominant component of the sand is quartz in well-rounded grains, but felspar- and hornblende-grains also occur, with a fair proportion of calcareous grains. The

latter are only casts of marine foraminiferal shells, and help to suggest the site of origin of the sands with which they are intimately mixed

As is characteristic of all aeolian sands, the sand-grains are well and uniformly rounded, by the ceaseless attrition and sorting they have received during their inland drift. In other respects the Rajputana sand is indistinguishable from the sand of the sea-shore.

Origin of the Rajputana desert.

The origin of the Indian desert is attributed, in the first instance, to a long-continued and extreme degree of aridity of the region, combined with the sand-drifting action of the south-west monsoon winds, which sweep through Rajputana for several months of the year without precipitating any part of their contained moisture. These winds transport inland clouds of dust and sand-particles, derived in a great measure from the Rann of Cutch and from the sea-coast, and in part also from the basin of the Lower Indus There is but little rainfall in Rajputana—the mean annual fall being not much above 5 inches—and consequently no water-action to carry off the detritus to the sea, which has hence gone on accumulating year after year. A certain proportion of the desert sand is derived from the weathered débris of the rocky prominences of this tract, which are subject to the great diurnal as well as seasonal alternations of temperature characteristic of all arid regions. The daily variation of heat and cold in some parts of Rajputana often amounts to 100° Fahr. in the course of a few hours. The seasonal alternation is greater. This leads to a mechanical disintegration and *desquamation* of the rocks, producing an abundance of loose debris, which there is no chemical or organic (or *humus*) action to convert into a soil-cap

The desert is not altogether, as the name implies, a desolate treeless waste, but does support a thin scrubby vegetation here and there, which serves to relieve the usually dreary and monotonous aspects of its limitless expanses; while, in the neighbourhood of the big Rajputana cities, the soil is of such fertility that it supports a fairly large amount of cultivation. Wells of good water abound in some places, admitting of some measure of well-irrigation.

Besides the above-described features of the great Indian desert, the Thar offers instructive illustrations of the action of aeolian agencies. As one passes from Gujarat or even Central India to the country west and south of the Aravallis one cannot fail to notice the striking change in the topography that suddenly becomes apparent, in the bare and bold hill-masses and the peculiar sand-blasted, treeless landscapes one sees for miles around under a clear, cloudless sky. Equally apparent is the abundance of mechanical débris, produced by the powerful insolation, the disintegration of the bare rock-surface by desquamation, the saline and alkaline efflorescences of many parts, the general absence of soil and humus. A more subtle and less easily understood phenomenon of the Rajputana desert is the growing salinity of its lake-basins by wind-borne salt dust from the sea-coasts.[1]

The Rann of Cutch.

This vast desiccated plain terminates to the south-west in the broad depression of the Rann of Cutch, another tract of the Indo-Gangetic depression which owes its present condition to the geological processes of the Pleistocene age. This tract is a saline marshy plain scarcely above the sea-level, dry at one part of the year and covered by water at the other part. It was once an inlet of the Arabian Sea, which has now been silted up by the enormous volume of detritus poured into it by the small rivers discharging into it from the east and north-east. From November to March, that is, during the period of the north-east or retreating monsoons, the Rann is a barren tract of dry salt-encrusted mud, presenting aspects of almost inconceivable desolation "Its flat unbroken surface of dark silt, baked by the sun and blistered by saline incrustations, is varied only by the mirage and great tracts of dazzlingly white salt or extensive but shallow flashes of concentrated brine; its intense silent desolation is oppressive, and save by chance a slowly passing caravan of camels or some herd of wild asses, there is nothing beyond a few bleached skeletons of cattle, salt dried fish, or remains of insects brought down by floods, to maintain a distant and dismal connection between it and life, which it is utterly

[1] *Rec. G S.I.* vol. x. pt. 1, 1877, and *Mem. G S I.* vol. xxxv. pt. 1. 1902.

unfit to support"[1] During the other half of the year it is flooded by the waters of the rivers that are held back owing to the rise of the sea by the south-west monsoon gales A very little depression of this tract would be enough to convert Kathiawar and Cutch into islands On the other hand, if depression does not take place, the greater part of the surface of the Rann will be gradually raised by the silts brought by the rivers with each flood, and in course of time converted into an arable tract, above the reach of the sea, a continuation of the alluvial soil of Gujarat.

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[1] Wynne, *Mem G.S.I.* vol. ix. 1872.

CHAPTER XXIII

THE PLEISTOCENE SYSTEM (*Continued*)

LATERITE

Laterite, a regolith peculiar to India.

In this chapter we shall consider laterite, a most wide-spread Pleistocene formation of the Peninsula and Burma, a product of subaerial alteration highly peculiar to India. Laterite is a form of regolith peculiar to India and a few other tropical countries. Its universal distribution within the area of the Peninsula, and the economic considerations that have of late gathered round it, no less than its obscure mode of origin, combine to make laterite an important subject of study in the geology of India.

Composition.

Laterite is a kind of vesicular clayey rock, composed essentially of a mixture of the hydrated oxides of alumina and iron with, often a small percentage of other oxides, chief among which are manganese and titanium oxides. The two first-named oxides are present in variable ratios, often mutually excluding each other; hence we have numerous varieties of laterite which have bauxite at one end and an indefinite mixture of ferric hydroxides at the other. The iron oxide generally preponderates and gives to the rock its prevailing red colours; at places the iron has concentrated in oolitic concretions, at other places it is completely removed, leaving the rock bleached, white or mottled. At some places again the iron is replaced by manganese oxides; in the lateritic cap over the Dharwar rocks this is particularly the case. There is no clay (kaolin) in typical laterites, the silica present is coloidal and mechanically associated. According to the preponderance of any of the oxides, iron, alumina, or manganese, at the different centres, the rock constitutes a workable ore of that metal. Usually between the laterite cap and the underlying basalt or other rocks over which it rests, there is a

lithomarge-like rock, or bole, a sort of a transitional product, showing gradual passage of the underlying rock (basalt or gneiss) into laterite.

Laterite has the peculiar property of being soft when newly quarried, but becoming hard and compact on exposure to the air. On account of this property it is usually cut in the form of bricks for building purposes. Also loose fragments and pebbles of the rock tend to re-cement themselves into solid masses as compact as the original rock.

Distribution of laterite

Laterite occurs principally as a cap on the summit of the basaltic hills and plateaus of the highlands of the Deccan, Central India, and Central Provinces In its best and most typical development it occurs on the hills of the Bombay Deccan. In all these situations it is found capping the highest flows of the Deccan Traps. The height at which laterite is found varies from about 2000 feet to 5000 feet and considerably higher, if the ferruginous clays and lithomarges of the Nilgiri mountains are to be considered as one of the many modifications of this rock. In thickness the laterite cap varies from 50 to nearly 200 feet; some of these are of small lateral extent, but others are very extensive and individual beds are often seen covering an immense surface of the country continuously. Laterite is by no means confined to the Deccan Trap area, but is found to extend in isolated outcrops from as far north as the Rajmahal hills in Bengal[1] to the southern extremity of the Peninsula. In these localities the laterite rests over formations of various ages and of varying lithological composition, *e.g.* Archaean gneiss, Dharwar schist, Gondwana clays, etc. Laterite is of fairly wide occurrence in parts of Burma also.

High-level laterite and low-level laterite.

The laterite of the above-noted areas is all of high level, *i.e.* it never occurs on situations below 2000 feet above the sea level. The rock characteristic of these occurrences is of massive homogeneous grain and of uniform composition. This laterite is distinguished as *high-level laterite*; to differentiate it from the *low-level laterite* that occurs on the coastal

[1] These hills are for the most part composed of Jurassic traps, in addition to a substratum of Gondwana rocks, the summit of the traps is covered with laterite.

wlands on both sides of the Peninsula, east and west. On
ie Malabar side its occurrences are few and isolated, but on
ie eastern coast the laterite occurs almost everywhere
sing from beneath the alluvial tracts which fringe the coast.
aterite of the low-level kind occurs also in Burma, in Pegu,
nd Martaban. Low-level laterite differs from the high-level
ock in being much less massive and in being of detrital
rigin, from its being formed of the products of mechanical
isintegration of the high-level laterite As a rock-type,
iterite cannot be said to constitute a distinct petrological
pecies ; it shows a great deal of variation from place to place,
s regards both its structure and its composition, and no broad
lassification of the varieties is possible ; but the above
istinction of the two types of high and low level is well
stablished, and is based on the geological difference of age
s well as the origin of the two types.

Theories of the origin of laterite.

The origin of laterite is intimately connected with the
hysical, climatic, and denudational processes at work in India.
'he subject is full of difficulties, and although many hypo-
heses have been advanced by different geologists, the origin
f the (high-level) laterite is as yet a much-debated question.
)ne source of difficulty lies in the segregative changes which
re constantly going on in this rock, which obliterate the
reviously acquired structures and bring about a fresh
earrangement of the constituents of the rock. It is probable
hat laterites of all the different places have not had one
ommon origin, and that widely divergent views are possible
or the origin of the different varieties.

From its vesicular structure and its frequent association
vith basalts, it was at first thought to be a volcanic rock Its
ubaerial nature was, however, soon recognised beyond doubt,
nd later on it was thought to be an ordinary sedimentary
ormation deposited either in running water, or in lakes and
epressions on the surface of the traps. Still later views regard
he rock as the result of the subaerial decomposition *in situ* of
asalt and other aluminous rocks under a warm, humid and
nonsoonic climate. Under such conditions of climate the
lecomposition of the silicates, especially the aluminous
ilicates of crystalline rocks, goes a step further, and instead

of kaolin being the final product of decomposition, it is further broken up into silica and the hydrated oxide of alumina (bauxite). The vital action of low forms of vegetable life was at one time suggested as supplying the energy necessary for the breaking-up of the silicates to this last stage. The silica is removed in solution, and the salts of alkalies and alkaline earths, derived from the decomposition of the ferromagnesium and aluminous silicates, are dissolved away by percolating water The remaining alumina and iron oxides become more and more concentrated and become mechanically mixed with the other products liberated in the process of decomposition. The vesicular or porous structure, so characteristic of laterite, is due to molecular segregation taking place among the products left behind. For the latest views on laterite and bauxite of India see Dr C. S Fox's Memoir.[1]

Mr. J. M. Maclaren[2] declares that laterite deposits are due to the metasomatic replacement (in some cases by mechanical replacement) of the soil or sub-soil by the agency of mineralised solutions brought up by the underground percolating waters ascending by capillary action to the superficial zone.

From the highly variable nature of this peculiar rock, it is possible that every one of the above causes may have operated in the production of the laterites of different parts according to particular local conditions. Dr. Leigh Fermor is of this opinion, and has declared that no one hypothesis will be able to account for all the laterite deposits of the Indian Peninsula.

The age of laterite.

The age of the existing high-level laterite cap is not determinable with certainty; in part it may be Pliocene, or even older, in part its age is Post-Tertiary (Pleistocene) or somewhat later, and it is probable that some of it may still be forming at the present day; that of the low-level, coastal laterite must obviously be still younger. The earliest remains of prehistoric man in the shape of stone implements of the *Palaeolithic* type are found embedded in large numbers in the low-lying laterite

There are evidences, however, that important masses of

[1] "Bauxite and Aluminous Laterite Occurrences of India," *Mem. G.S.I.* vol. xlix. pt. 1, chap i. 1923

[2] *Geological Magazine*, Dec V vol. iii. 1906.

erite were formed in the Eocene, and even in earlier ages. subaerial mode of origin under the above conditions ng granted, there is no reason why it should be restricted any particular age only.. According to several authorities erite is seen at several other horizons in the stratigraphical ord of India, especially those marking breaks or unconmities when the old land-surfaces were exposed for long rations to the action of the subaerial agents of change. ferruginous lateritic gravel bed among the rock-records of st ages is, therefore, held to be of the same significance as unconformity conglomerate.

Economics.

As stated above, laterite is at times, according to conditions vouring the concentration of any particular metallic oxide, valuable ore of iron or an ore of aluminium and manganese. ie use of laterite as an ore of iron is of very old standing, it its recognition as a source of alumina is due to Sir T. H. olland, and of manganese to Dr. L. Fermor. In several rts of southern India and Burma laterite is quarried for e as a building stone from the facility with which it can be t into bricks. In fact the term laterite originally has come om the Latin word *later*, a brick.

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CHAPTER XXIV

PLEISTOCENE AND RECENT

Examples of Pleistocene and Recent deposits

AMONG the Pleistocene and Recent deposits of India are the following, each of which in its respective locality is a formation of some importance. The high-level river-terraces of the Upper Sutlej and other Himalayan rivers and of the Narbada and Tapti among the Peninsular rivers; the lacustrine deposits (*Upper Karewa*) of the Upper Jhelum valley in Kashmir and the similar accumulations (*Tanr*) in the Nepal valley; the foraminiferal sandstone (*Porbander stone*) of the Kathiawar coast and the *Teris* of the Tinnevelli and Travancore coasts; the aeolian deposits of the Godavari, Kistna and Cauvery banks (resembling the *Bhur* of the Ganges valley) and the *loess* deposits of the Salt-Range and of Baluchistan; the extensive fluvio-glacial deposits of the Potwar-plateau; the stalagmitic cave-deposits of the Karnul district; the black cotton-soil or *Regur* of Gujarat and the Deccan; the great gravel-slopes (*daman*) of the Baluchistan hills, etc., are examples, among many others, of the Pleistocene and later deposits of India, each of which require a brief notice in the present chapter.

Alluvium of the Upper Sutlej.

Ossiferous clays, sands and gravels, the remains of the Pleistocene alluvium of the Upper Sutlej,[1] are found in the Hundes province of the Central Himalayas covering several hundreds of square miles and resting at a great height above the present level of the river-bed. These deposits were laid down in the broad basin of the Upper Sutlej while it was at a considerably higher level, enclosing numerous relics of the living beings that peopled this part of the Himalayas. The old alluvium of the river is now being

[1] *Rec. G.S I.* vol. xiv pt. 2, 1881.

ɜeply trenched by the very Sutlej which has already cut out of a picturesque and deep, narrow gorge some 3000 feet in depth.

Tapti and Narbada.

In the broad basins of many of the Peninsular rivers large ɪtches of ancient alluvium occur, characterised by the ɾesence of fossils belonging to extinct species of animals. f these the old alluvial remains of the Narbada and Tapti ·e remarkable as lying in deep rock-basins, at considerable evations above their present bed. Among other vertebrate ɑd mammalian fossils,[1] these ancient river sediments have reserved the earliest undoubted traces of man's existence. cattered in their alluvia are the stone-knives, hatchets, ɾrows and other implements of man which he manufactured ut of any hard stone that he came across, whether it was uddapah quartzite or Vindhyan sandstone, or the amygda-ɔidal agates.

There is some proof that the Narbada in those days was onfluent with the Tapti, and that its separation into a distinct hannel was effected at a comparatively late date by earth-ɪovements. That the course of the Narbada has undergone serious disturbance during late geological time is corro-ɪorated by another piece of evidence, namely the precipitous alls of this river at Jabalpur.

The Karewas of Kashmir.

The valley of Kashmir is an alluvium-filled basin, a large part ɪf which is of recent formation by the river Jhelum More than ɪalf of its area, however, is occupied by outliers of a distinctly ɪlder alluvium, which forms mounds or platforms, sloping ɪway from the high mountains that border that valley on ɪll sides. These deposits, known in Kashmir language as *Karewas*,[2] are composed of fine silty clays with sand and ɡravel, the coarse detritus being, as a rule, restricted to the ɔeripheral parts of the valley, while the finer variety prevails ɪowards the central parts. The bedding of the Karewas is 'or the greater part almost horizontal, but where they abut ɪpon the Pir Panjal, or the mountains of the south-east border ɔf the valley, they show evidence of a good deal of upheaval,

[1] *Crocodilus, Trionyx, Pangshura, Ursus, Bubalus, Bos, Equus, Sus, Cervus, Elephas, Hippopotamus* and *Rhinoceros* Besides these, shells of land-molluscs such as *Melania, Planorbis, Paludina, Lymnia, Bullinus, Unio* are found in the alluvium of the Narbada.

[2] F Drew, *Jammu and Kashmir Territories*, p. 210, 1875.

dipping sometimes as much as 40° at some places, the direction of the dip being towards the valley.[1]

Middlemiss' work in the Pir Panjal and elsewhere has greatly modified the views regarding the age and thickness of these deposits. He has shown that their thickness amounts to 3000 feet at least, and that the lower part of the Karewa deposits is considerably older than any of the glacial moraines on the Pir Panjal. It is evident, therefore, that the Karewas must include deposits older than the Pleistocene—Upper Siwalik.

The Karewas, in their upper beds, are supposed to be the relics of an old extensive lacustrine formation which once filled the whole valley of Kashmir from end to end to a depth of more than a 1000 feet This old alluvium has been subsequently dissected, and in a great measure removed by subaerial denudation as well as by the modern Jhelum into the Karewa outliers of to-day For further information regarding Karewa see Chapter XXVII

Old alluvial deposits, to which a similar origin is ascribed, are found in the Nepal valley, and are known there under the local name of *Tanr* They contain a few peat and phosphatic beds.

Porbander stone (Miliolite). In a previous chapter it was mentioned that all along the eastern coast of India, from the Ganges delta to the extremity of the Peninsula, there is a broad strip of Tertiary and Post-Tertiary alluvium containing marine shells and other fossils. The Tertiary part of these deposits has been described already under the title of the Cuddalore series, in Chapter XVII.; the remaining younger part occupies small tracts both on the east and west coast. That on the east coast, however, assumes a considerable width and forms large tracts of fertile country from the Mahanadi to the Cape. On the Malabar coast this alluvial belt is very meagre and is confined to the immediate vicinity of the coasts except at its north end, where it widens out into the alluvial flats of Gujarat. On the Kathiawar coast at some places a kind of coastal deposit

[1] Recent investigations have revealed some Karewa deposits even on the summit of the Pir Panjal (11,000 ft), thus proving that the latter mountains have been elevated nearly 5000 ft. since the Karewas were deposited. *Rec. G S I* vol xliv, pt. 1, 1914, Director's Report.

occurs known as the *Porbander stone* (sometimes also as *Miliolite*), which is noteworthy. It is composed of calcareous wind-blown sand, the sand grains being largely made up of the casts of foraminifers, the whole compacted into a white or cream-coloured, rudely-bedded freestone. From its softness and the ease with which it receives dressing and ornamental treatment, it is a favourite material for architectural purposes in many parts of the Bombay Presidency.

Sand-dunes.

Sand-dunes are a common feature along the Indian coasts, particularly on the Malabar coast, where they have helped to form a large number of lagoons and backwaters, which form such a prominent feature of the western coast of India In Orissa there are several parallel ridges of sand-dunes on the plains fronting the coast which are held to indicate the successive positions of the coast-line. Sand-loving grasses and other vegetation help to check the further progress of the dunes inland.

Sand-dunes are also met with in the *interior* of the Peninsula, in the broad valleys of the Kistna, Godavari, etc. The sand is blown there by the strong winds blowing through these valleys during the hot-weather months A large volume of sand is thus transported and accumulated along the river courses, which are unable to sweep them away (cf. *Bhur* land of the Ganges valley).

The peculiar form of sand-hills known as *Teri* on the Tinnevelli coast is also of the same origin.

Loess

In the country to the west of the Indus in the N W. Punjab and on the Salt-Range, there are subaerial Pleistocene accumulations of the nature of loess, a loose unstratified earthy or sandy deposit but little differing in composition from the alluvium of the plains. Loess, however, differs from the latter in its situation at all levels above the general surface of the plains and in its being usually traversed by fine holes or tubes left by the roots of the grasses growing upon it The lower parts of Baluchistan are largely covered with wind-blown, more or less calcareous and sandy earth, unstratified and loosely consolidated. On the flat plateau top of the Salt-Range loess is a very widespread superficial deposit, and on many plateaus, which form the summit of this range,

the accumulation of loess from the dust and sand blown from the Punjab plains is yet in progress. The inequalities of the surface, produced by its irregular distribution, are the cause of the numerous shallow lakes [1] on the summit of the Salt-Range. Loess is also a prevalent superficial formation in the country bordering the Salt-Range to its north.

The conditions that have favoured the growth of loess in these parts are their general aridity and long seasons of drought. These give rise to dust-storms of great violence in the hot-weather months preceding the monsoons, which transport vast clouds of dust and silt from the sun-baked plains and dried-up river-basins, and heap them on any elevated ground or accidental situation. The isolated dust-mounds one notices in some parts of the Punjab are attributable to this cause.

Potwar fluvio-glacial deposits

Potwar [2] is an elevated plain lying between the northern slopes of the Salt-Range and the Rawalpindi district. A few feet below the ordinary Pleistocene alluvium of some parts of these plains is found a curious intermixture of large blocks of rocks with small pebbles and boulders, the whole embedded in a fine-grained clayey matrix. The material of the blocks suggests their derivation from the high central ranges of the Himalayas, while their size suggests the action of floating ice, the only agency which could transport to such distances such immense rock-masses. The Indus river is noted for floods of extraordinary severity (owing to accidental dams in the upper narrow gorge-like parts of its channel or that of any of its tributaries).[3] Many such floods have been known since historic times, and some have been recorded in the chronicles. The water so held up by the dam spreads out into a wide lake-like expanse in the broader part of the valley above the gorge. In the Pleistocene times, when, as has been shown in a previous chapter, the Himalayas were experiencing arctic conditions of climate, the surface of the lake would be frozen. The

[1] *Rec G S I.* vol xl pt 1, 1910.

[2] *Rec. G S I* vol x. pt. 3, 1877, and *Rec. G S.I.* vol. xiii. pt 4, 1880.

[3] For an interesting account of some of the recent disastrous floods of the Indus and their cause, obtained from eye-witnesses and from personal observations, see Drew, *Jammu and Kashmir Territories.* London, 1875

lden draining of the lake, consequent on the removal of
e obstacle by the constantly increasing pressure of the
aters resulting from the melting of the ice in springtime,
ould result in the tearing off of blocks and masses of
cks frozen in and surrounded by the ice The rushing
bacle would float down the ice-blocks with the enclosed
ocks of rock, to be dropped where the ice melted and the
ater had not velocity enough to carry or push them further.
is would, of course, happen at the site where the river
nerged from its mountain-track and entered the plains.
e above is regarded as the true explanation of the origin
the Potwar deposits. It thus furnishes us with another
gent evidence of the existence of glacial conditions, at any
ne in the Himalayas.[1]

Caves.[2] But few caves of palaeontological interest exist India, and of these only one has received the attention geologists. The caves in other countries have yielded luable ossiferous stalagmitic deposits, throwing much light the animal population of late geological times, their habits, ode of life, etc. The only instances of the Pleistocene caves e a few caverns in the Karnul [3] district in the neighbour-od of Banaganapalli, in a limestone belonging to the Kurnool ries. In the stalagmite at the floor, there occurs a large semblage of bones belonging to a mixture of recent and b-recent species of genera, like *Viverra*, *Hystrix*, *Sus*, *hinoceros* (extinct), and *Cynocephalus*, *Equus*, *Hyaena*, *Manis*, c. (living species).

Cave deposits.

A small cave in a limestone belonging to the Triassic age, curring in the neighbourhood of Srinagar, near Harwan, as recently found to contain mammalian bones on its floor. ey included the remains of sub-recent species as *Cervus istotelis* (Sambur), *Sus scropha* (European pig), and an known antelope.

[1] Middlemiss is not disposed to regard the Potwar blocks as ice-transported d as "erratics." He believes them to be simply weathered-out masses granite *in situ*. In the Hazara he found what were thought to be *erratics* Theobald, to be only the weathered outcrops of granite-veins that had netrated the rocks of the country. *Mem. G.S.I.* vol. xxvi. 1896.

[2] *Rec. G.S.I* vol. xix. pt 2, 1886; *Pal. Ind.* sers. x. vol. iv pt. 2, 1886.

[3] *Mem. G S I* vol. iv. pp. 183 and 357, and vol. vi. p 235; *Rec.* vol. iv. 80, 1871.

Regur.

Among the residual soils of India there is one variety which is of special geological interest. This is the black soil, or *Regur*,[1] of many parts of Gujarat and Deccan, and the other "Cotton districts" of the Peninsula Regur is a highly argillaceous, somewhat calcareous, very fine-grained black soil. It is extremely sticky when wetted, and retains its moisture for a very long time. Among its accessory constituents are a high percentage of calcium and magnesium carbonates, iron, and a very large admixture of organic matter, sometimes amounting to 10 per cent. It is owing to the two latter constituents that the prevailing dark, often black, colour is due The black cotton soil is credited with an extraordinary degree of fertility by the people; it is in some cases known to have supported agriculture for centuries without manuring or being left fallow, and with no apparent sign of exhaustion or impoverishment.

The origin of Regur.

The origin of this soil is ascribed to long-continued surface-action on rocks like the Deccan Traps and other Peninsular formations. The decomposition of basalts *in situ*, and of aluminous rocks generally, would result in an argillaceous or clayey residue, which, by impregnation of decomposed organic matter, *humus*, resulting from ages of jungle growth over it, together with some iron, would assume the character of Regur.

"Daman" slopes.

Alluvial fans or taluses fringing the mountains of Baluchistan, and known as "Daman," are another example of Pleistocene deposits These are a very prominent feature of the hilly parts of Baluchistan where the great aridity and drought favour the accumulation of fresh angular débris in enormous heaps at the foot of the hills Wells that are commonly excavated in these gravel slopes (and which are known as *Karez*) illustrate a peculiar kind of artesian action. The Karez is merely a long underground, almost horizontal, tunnel-like bore driven into the sloping talus till it reaches the level of permanent saturation of water, which is held in the loose porous gravel. The water is found at a sufficient pressure to make it flow at the mouth of the well The underground tunnel may be several miles in

[1] From Telugu word *Regada*.

th and connected with the surface by a number of ›-holes [1]

The Human epoch.

ı the foregoing account of the later geological deposits of ıa there is everywhere a gradual passage from the Pleisto- › to the Recent, and from that to Prehistoric. These ods overlap each other much as do the periods of human ory As in the other parts of the world, the Pleistocene ndia also is distinguished by the presence of Man and is wn as the Human epoch.

[an's existence is revealed by a number of his relics pre- ׳ed among the gravels of such rivers as the Narbada and lavari, or in other superficial alluvia, both in South and ·th India These archaic human relics consist of various ıe implements that prehistoric man used in his daily life, ging from rude stone-chippings and flakes to skilfully ıioned and even polished instruments like knives, celts, ıpers, arrow-heads, spears, needles, etc., manufactured out ıtone or metal or bone These instruments ("artefacts") ome more and more numerous, more widely scattered, and ıce an increasing degree of skill in their making and in ır manipulation as we ascend to newer and younger nations. This testimony of his handwork furnishes us h the best basis for the classification of this period into ee epochs:

3. Iron Age.
2. Bronze Age.
1. Stone Age. { *Neolithic*—polished tools. / *Palaeolithic*—rude tools. }

:hese three stages of the Human epoch, decipherable in Pleistocene records of the other parts of the world, are ognisable in the numerous relics of man discovered in lıa. Besides bronze implements, the primitive Indian d implements made of copper, a material which he obtained m some deposits of native copper in Southern India.[2]

[1] Vredenburg, *Mem* vol. xxxii. pt. 1, 1901 · Oldham, *Rec G SI* vol xxv. l, 1892

[2] *Prehistoric and Protohistoric Relics of Southern India*, by R B. Foote, lras, 1915; *Old Chipped Stones of India*, by A. C Logan, Calcutta, 1906.

The existence of man in an age earlier than the older alluvia of the Narbada and Godavari is a matter of conjecture only. Whether he was a witness of nature's last great phenomenon, the erection of the Himalayan chain to its present height, or whether he was a contemporary of the *Sivatherium* or the *Stegodon*, is a profoundly interesting speculation, but for which no clue has been hitherto discovered The question has hardly received any attention in India, and for any elucidation it must await the solution of the great problem of the glacial man in Europe.

Here, however, we reach the limits of geological inquiry. Further inquiry lies in the domains of anthropology and archaeology.[1]

Few changes of geography have occurred in India since the Pleistocene. After the great revolutions at the end of the Pliocene, the present seems to be an era of geological repose. A few minor warpings or oscillations in the Peninsula; the extinction of a few species; the migration and redistribution of others, some changes in the courses of rivers, the degradation of their channels a few feet lower, and the extension of their deltas; the silting up of the Rann of Cutch; a few great earthquakes; the eruptions of the Barren Island and other minor geological and geographical changes are all that the geologist has to notice since the advent of man in India.

REFERENCES

References to the various subjects treated in this chapter have been given against each.

[1] *Ancient Hunters*, W. J Sollas (Macmillan), 1924.

CHAPTER XXV.

PHYSIOGRAPHY

In the light of what we have seen of the geological history of India, a brief re-examination of the main physiographic features of the country will be of interest Every geological age has its own physiography, and, therefore, the present surface features of India are the outcome, in a great measure, of the latest chapters of its geological history

Principles of physiography illustrated by India

Physiography is that branch of geology which deals with the development of the existing contours of the land part of the globe. In the main, dry land owes its existence *en masse* to earth-movements, while the present details of topography, its scenery and its landscapes, are due to the action of the various weathering agents In the case of elevated or mountainous regions of recent upheaval, the main features are, of course, due to hypogene agencies ; but in old continental areas, which have not been subject to crustal deformation for long ages, the epigene forces have been the chief agents of earth-sculpture. In the latter class of earth-features there is no correspondence observable between the external configuration of the regions and their internal geological structure. Here the high ground does not correspond to anticlinal, or the hollows and depressions of the surface to synclinal folds. The accumulation of the eroded products derived from the degradation of the elevated tracts by the subaerial, meteoric agencies in a low, broad zone of lodgment, gives rise to a third order of land-forms—the plains of alluvial accumulation.

The three physiographic divisions of India afford most pertinent illustrations of the main principles of physiography stated above. The prominent features of the extra-Peninsula, the great mountain border of India, are those due to upheaval

of the crust in late Tertiary times, modified to some extent by the denuding agents which have since been operating on them; those of the Peninsula are the results of subaerial denudation of a long cycle of geological ages, modified in some cases by volcanic, and in others by sedimentary accumulations; while the great plains of India, dividing these two regions, owe their formation to sedimentary deposition alone, their persistent flatness being entirely due to the aggrading work of the rivers of the Indus-Ganges system.

Whatever may be the cause of the upward and downward movements of the earth's surface, which have originated the broad features of its relief—the great ocean basins, continents and mountains—whether it be the contraction of the earth due to its loss of heat, or the disturbance of its isostatic conditions, movements of depression must always be in excess of elevation In fact, uplift can only take place on a minor scale and only locally, where any two adjacent master-segments of the earth's sphere in their subsidence squeeze between them, and ridge up an intervening area by the enormous tangential thrusts involved in the sinking of the former. On this view, briefly expressed, the Himalayas have come into existence by the compression of the geosynclinal belt of sediments, a comparatively weak zone in the earth's circumference, between the great plateau of Central Asia and the horst of Gondwanaland.

The main elements of the physiography of a country are five.

(1) Mountains. (2) Plateaus and Plains.
(3) Valleys. (4) Basins
(5) Coast-lines.

1. MOUNTAINS

Mountains may be (1) original or tectonic, or (2) subsequent or relict. The student already knows that these two types characterise the two major divisions of India Tectonic mountains include (*a*) accumulation-mountains and (*b*) deformation-mountains. Volcanoes, dunes or sand-hills and moraines are examples of the former, while mountains

roduced by the deformation or wrinkling of the earth's rust are examples of the tectonic type In the latter the elief of the land is closely connected with its geological tructure, *i.e.* the strike, or trend, of these mountains is quite onformable with their axis of uplift. They are divisible into wo classes . (i) folded mountains, and (ii) dislocation-moun-ains. Of these, the first are by far the most important, omprising all the great mountain-chains of the earth. The Himalayas, as also all the other mountain-systems of the xtra-Peninsular area, are of this type.

The structure of the Himalayas.

The internal structure of the Himalayas has not been the ubject of such an exhaustive study and investigation as that which has so far unravelled the inner architecture of the Alps. A great deal of investigation in the central ranges especially —the zone of most complex flexures—remains to be done, before which it is possible to say anything regarding the tructure of these mountains, except in very general terms.

The structure of the outer ranges is of great simplicity, They are made up of a series of broad anticlines and synclines of the normal type, a modification of the Jura type of mountain-structure. It is a well-established characteristic of he folds of this part of the Himalayas that the anticlines are ften faulted steeply in their outer or southern limbs, the aulted scarp lying in juxtaposition with a much younger series f rocks. This zone is succeeded, *e.g.* in the Pir Panjal system f ranges, by a closer, and much less symmetrical, system of olds and overfolds of the isoclinal type broken asunder by a umber of reversed faults that have passed into thrust-planes.

These outer ranges are separated by narrow longitudinal ectonic valleys or depressions called *Duns*. The reversed aults mentioned above are a characteristic feature in the ectonics of the sub-Himalayan ranges. The most prominent f them is the Main Boundary Fault, which extends along he whole length of the mountain from the Punjab to their xtremity in the east. We have seen on pages 29 and 233 he true nature of these faults and the significance attached o them.

Many of the ranges in the outer Himalayas, and several f the middle Himalayas as well, are of *orthoclinal* type of

structure, *i.e.* they have a steep scarp on the side facing the plains and a gentle inclination on the opposite side facing Tibet. As we approach closer to the central crystalline axis of the mountains, all simplicity disappears; there is no longer any correspondence between the strike of the rocks and the lineation of the ranges, which depart more and more from their internal structure and show repeated branching and ramification The folds become more densely packed and overfolds, inversions, and thrust-planes assume an increasing degree of intensity Plutonic intrusions become common, increase in magnitude, and serve to make the structure still more complex by the accompanying metamorphosis of the surrounding rocks, obliterating all distinction between the crystalline and the sedimentary rocks of these zones.

The northern flank of the Himalayas, revealed in the gigantic Tibetan escarpments which front the Punjab Himalayas, such as those of Spiti, Garhwal and Kumaon, shows again a somewhat simpler type of structure, but beyond this not much is known regarding their architecture.

To get an idea of the structure of the Himalayas the student must study carefully the transverse sections across the Himalayas, given in *Mem.* XXIV p. 183, 1890, of the Geological Survey of India, by Middlemiss, in which the structure of the sub-Himalayan ranges and their relation to the inner mountains are most clearly exposed The sections are reproduced on a very much reduced scale in Figs. 28 and 29 of this book.

Mountain ranges which are the result of one upheaval are known as *Monogenetic*; those of several successive upheavals *Polygenetic* The two outer parallel belts of deposits of the Sirmur and Siwalik systems very clearly mark two successive phases of uplift subsequent to their deposition

The mountain-ranges of Sind-Baluchistan and Burma, to the west and the east of the Himalayas, are of a more simple geological structure, and, in the succession of normal anticlines and synclines of which they are built up, recall the type of mountain-structure known as the Appalachian. In the former area, especially, the mountains reveal a very simple type of topography. Here the hill-ranges are anticlines with

intervening synclines as valleys. The sides of the mountains, again, are a succession of dip-slopes.

In regions of more advanced topography, with greater rainfall and a consequently greater activity of subaerial denudation, *e.g.* the outer and middle Himalayas, this state of things is quite reversed, and the valleys and depressions are carved out of anticlinal tops while the more rigid, compressed synclinal systems of strata stand out as elevated ground

While the broad features of these regions are solely due to movements of uplift, the characteristic scenery of the mountains, the serried lines of range behind range, separated by deep defiles and valleys, the bewildering number of watersheds, peaks and passes and the other rugged features which give to the mountains their characteristic relief and outline, are the work of the eroding agents, playing on rocks of different structures and varying hardnesses. [1]

Among the mountains of the extra-Peninsula, the Salt-Range must be held as an illustration of a dislocation-mountain. Its orthoclinal outline, *i.e.* its steep southern scarp and the long gentle northern slope, suggests that these mountains are the result of a monoclinal uplift combined with vertical dislocation along their southern border, which has depressed the other half underneath the plains of India. Similarly the Assam ranges at the north-east probably have the same origin These two ranges, at either extremity of the plains of India, share many common physical features and are somewhat unique in their physiography among the mountain-systems of India.

The mountains of the Peninsula.

With the exception of the now deeply eroded Aravalli chain, all the other mountains of the Peninsula are mere hills of circumdenudation, the relics of the old high plateaus of South India. The Aravalli region of the present day owes its features to an enormous amount of subaerial degradation, which has all but levelled down an ancient mountain-chain

[1] The extremely rugged and serrated aspect of the lofty central ranges of the Himalayas, which are constantly subject to the action of snow and ice, contrasts strongly with the comparatively smooth and even outlines of the lesser Himalayas. The scenery of the outer Siwalik ranges is of a different description, the most conspicuous feature in it being a succession of escarpments and dip-slopes with broad longitudinal valleys in between.

into a type of land-form known as *Peneplain*. The hills south of the Vindhyas (with the possible exception of the Satpuras) are mere prominences or outliers left standing while the surrounding parts have disappeared in the prolonged denudation which these regions have undergone. Many of these "mountains" are to be regarded as ridges between two opposing drainages. It is this circumstance which, first of all, determined their trend and has subsequently tended to preserve them as mountains.

2. THE PLATEAUS AND PLAINS

Plateaus are elevated plains having an altitude of more than 1000 feet. They may be of two kinds. (1) Plateaus or plains of accumulation, whether sedimentary or volcanic, and (2) plateaus and plains of erosion.

Volcanic plateau. The best example of a plateau of accumulation in India is the volcanic plateau of the Deccan, built up of horizontal lava-sheets, now dissected into uplands, hills, valleys and plains. Its external configuration corresponds exactly with the internal structure, in the flat table-topped hills and the well-cut stair-like hill-sides.

Erosion plateau. Plateaus of erosion result from the denudation of a tectonic mountain-chain to its base-level and its subsequent upheaval. In them there is no correspondence at all between the external relief and geological structure. Some parts of Rajputana afford an example of plain of erosion (pene-plain); parts of the Potwar plateau are another.

Plains of accumulation. The great plains of the Indus and Ganges are plains of sedimentary accumulation. The horizontally stratified alluvium has the simplest geological structure possible, which is in perfect agreement with their flat level surface.

3. VALLEYS

A valley is any hollow between two elevated tracts through which a stream or river flows. Valleys are grouped into two classes according to their origin:

(1) Tectonic, or Original Valleys.
(2) Erosion-Valleys.

Valley of Kashmir a tectonic valley.

Tectonic valleys are exceptional features in the physiography of a country. They owe their origin (1) to differential movements within the crust, such as the formation of synclines, which may be regarded as the complementary depression between two mountain-chains, or (2) to the irregular heaping-up of volcanic or morainic matter. The valley of Kashmir, as also some of the *Duns*, is an instance of tectonic valley, it being a synclinal trough enclosed between two contiguous anticlinal flexures. This aspect is, however, somewhat modified by the deep alluvium which has filled up the bottom as well as that which rests on the slopes of the bordering mountains. Some valleys also result from the irregular accumulation of volcanic or morainic material or of dunes of sand. Valleys which run along fault-planes or fissures in the crust are also tectonic valleys, being determined by movements of earth ; examples of such "fissure-valleys," according to some geologists, are afforded by the Narbada and Tapti (page 17). Such valleys are of very rare occurrence, however, though it is probable that the deep "rifts" of Baluchistan have originated in this manner.

Erosion-Valleys

Valleys of the Himalayas.

With the exceptions noted above, the great majority of the valleys of the Peninsula as well as of the extra-Peninsula are true erosion-valleys. The most prominent character of the major Himalayan valleys is their transverse course, *i.e.* they run across the strike of the mountain, in deep gorges or *cañons* that the rivers have cut for themselves by the slow, laborious process of vertical corrasion of their beds The only exceptions are the head portions of the Indus, the Ganges, and a few of their principal tributaries, which, for a part of their course, are longitudinal streams and flow parallel to the mountain-strike. The cause of this peculiarity of the Himalayan system of valleys has already been explained in Chapter I., as arising from the situation of the watershed to the north of the main axis of uplift of the Himalayas. Hence the zone of the highest, snow-capped ranges is deeply trenched by all the rivers as they descend from their watershed to the plains of India. The "curve of erosion" of these valleys, which are

The transverse gorges

yet in an immature stage of river-development, is, of course, most irregular and abounds in many inequalities The most conspicuous of these is an abrupt fall of nearly 5000 feet, which most rivers have, as they cross from the Central Himalayan zone into the Middle Himalayan zone, proving that the former zone is one of special uplift The same valleys, as they enter the end-portion of their mountain track—the Siwalik zone—cut through the very deposits which they themselves laid down at an earlier period of their history. Thus here also the apparently paradoxical circumstance is witnessed, that "the rivers are older than the hills which they traverse," which, on equally trustworthy evidences, is true for the whole of the Himalayas. (See Chapter I.)

The configuration of the Himalayan valleys.

The transverse gorges of the Himalayas, which are such characteristic features of the mountains, illustrate several interesting phases of river-action. In the first place their physical configuration in the eastern and western parts of the mountains is quite different. In the Kashmir Himalayas the upper courses of these streams show a series of abrupt alternations of deep precipitous U- or I-shaped gorges with broad, open V-shaped valleys, the latter always being found above the gorge-like portions In the Eastern Himalayas of Sikkim and Nepal, on the other hand, the valley courses are uniformly broad, with gently-sloping sides, and they do not exhibit the abrupt changes. This difference is due to the fact that the eastern part is a region of heavy rainfall, and hence the valley-sides are subject as much to erosion as the bed of the channel; here lateral corrasion is scarcely less marked than the vertical or downward corrasion of the bed In the Western Himalayas, on the other hand, the rainfall is much smaller. River-erosion is the chief agent of denudation, hence deep defiles are cut out of the hard crystalline rocks, and broad V-like valleys from the softer clay rocks The latter yield more readily to river-action because of the absence of any protective covering of vegetation.

The Himalayan valleys are all in an early or immature stage of their development; they have been rejuvenated again and again with every upheaval of the inner higher ranges, hence the varying lithological characters and structures

of the surface over which they flow have given rise to a number of waterfalls, cascades, and rapids in their courses. These will gradually disappear by the process of head-erosion, and in the later stages of valley-growth will be replaced by ravines and gorges. The narrow defiles of the Himalayan valleys are liable to be choked up by various accidental circumstances, such as landslips, glaciers, etc., and produce inundations of a terrific nature, when the dam is removed. Several of these floods are recorded within recent times[1] Many of the Himalayan valleys have been important high-roads of commerce with Tibet, Chinese Turkestan, etc , since very ancient times.

The deep gorges and *cañons*, so characteristic of the Salt-Range and Baluchistan, are due chiefly to climatic causes. The river at the bottom is actively corrading and lowering its bed, while there is no denuding agency to lower the banks in these arid, rainless countries, at an equal rate. The limestone rocks of the above districts have also been a factor in evolving these features.

Valleys of the Peninsula.

The valleys of the Peninsula offer a striking contrast to those of the extra-Peninsula, for the former have all reached the adult stage of their development The principal valleys of the Peninsula are broad and shallow, their gradients low, and by reason of the levelling process being in operation for a long series of ages, they are near the attainment of their base-level. Their *curve of erosion* is, in the majority of cases, a regular curve from the source to the mouth.

An exception to the above general case is afforded by the falls of the Narbada near Jabalpur. Their existence in a river channel of such great antiquity is inexplicable, and must be ascribed to recent tectonic disturbances (page 263).

The above remarks only apply to the valleys of the eastern drainage. The small but numerous streams that discharge into the Arabian Sea are all in a youthful state of development, being all actively eroding, torrential streams. Many of them abound in rapids and falls, of which the most famous are the Gersoppa Falls on the River Sharavati in the North Kanara district, but there are a number of other less-known instances This greater activity of the westerly flowing streams, as compared to the opposite system of drainage, is, of course, due to the former streams having to accomplish the same amount of descent to the coast as the latter, but within a far shorter distance of their watershed. Under such circumstances, a river performs much head-erosion, with the result that the watershed goes on continually receding.

[1] Chap. I p 34

This process will continue till the watershed has receded to about the middle of the Peninsula and brought the grade of the channels on either side to an approximate equality.

4. BASINS OR LAKES

Basins or lakes.

Lakes are larger or smaller depressions on the surface, the majority of which are filled with water, which, according to local conditions, may be fresh, brackish or salt Lakes are

Functions of lakes.

of importance as regulators of the water-supply of rivers, ensuring for them a more or less even volume of water at all times and seasons, and preventing sudden inundations and droughts Their effect on the hydrography of a country like India would be very beneficial, but as stated before, in the chapter on Physical Features, there are very few lakes in India of any considerable magnitude. Hence basins as a feature in the physiography of India play but little part. The origins of lakes are diverse The following are a few Indian examples :

Types of lakes.

(1) **Tectonic lakes** are due to differential earth-movements, some of which are of the nature of symmetrical troughs, while others are due to fracture or subsidence of the underlying strata. The old Pleistocene lakes of Kashmir, whose existence is inferred from the Karewa deposits of the present day, were of this type

(2) **Volcanic basins.** These are crater-lakes or explosion-crater lakes. The famous Lonar lake of salt water in the Buldana district, Berar, occupies a hollow which is supposed to have originated in a violent volcanic explosion—(*explosion-crater*).

(3) **Dissolution basins** These are due to a depression of the surface by underground solution of salt-deposits, or of soluble rocks like gypsum and limestone Some of the small lakes on the top of the Salt-Range may be due to this circumstance, aided by the irregular heaping of the loess deposits on its surface Some of the Kumaon lakes also are of this nature

(4) **Alluvial basins.** These are formed by the uneven deposition of sediments in deltas of rivers (Jhils) ; some lakes

are formed of the deserted loops of rivers (bayeau lakes), etc. The present lakes of the Kashmir valley are alluvial basins of this nature, while the Pangkong, Tsomorri and the Salt-Lake of Ladakh in Kashmir territory are explained by Drew to have had a somewhat different origin.[1] They have been formed by the alluvial fans from the side valleys (the tributaries) crossing the main valley and forming a dam which the waters of the main valley were unable to sweep away A number of the lakes of Tibet have also originated in this manner, while some are supposed to have originated by differential earth-movements—tectonic basins.

(5) **Aeolian basins** are hollows lying among wind-blown sand-heaps and dunes These are small and of temporary duration Some of the Salt-Range lakes are aeolian basins.

(6) **Rock-fall basins** are lakes produced by landslips or land-slides, causing the precipitation of large masses of rock across the stream-courses They are sometimes permanent The small lakes of Bundelkhand are examples. The Gohana lake of Garhwal, formed by a huge landslip across a tributary of the Ganges in 1893, is a recent instance

(7) **Glacial lakes.** They are often prevalent in districts which bear the marks of glaciation In some cases the hollows are of glacial erosion (true rock-basins),[2] in other cases they are due to heaps of morainic débris constituting a barrier across glacial streams. Numerous tarns and lakes on the north-east slopes of the Pir Panjal are examples Some of the Kumaon lakes are ascribed the latter origin. Old glacial basins, now converted into grassy meadows, and bounded by terminal moraines, are met with in front of some of the Himalayan glaciers (which are now retreating). Some of the *margs* of Kashmir are illustrations of moraine-bound basins

The Chilka lake of Orissa and the Pulicat lake of Nellore are lagoon-like sheets of brackish water which owe their origin to the deposition of *bars* or *spits* of sand, drifted up along the coast by the action of oblique sea-currents, across the mouths of small bays or inlets.

[1] *Jammu and Kashmir Territories*, London, 1875.

[2] The small lakes and tarns on the Pir Panjal are supposed to be of this description

5. COAST-LINES

The coast-lines of a country are the joint product of epigene and hypogene agents. A highly indented coast-line is generally due to subsidence, while a recently elevated coast is fronted by level plains or platforms, cliffs and raised beaches.

In old lands, which have not undergone recent alteration of level, many of the features are the result of the combined marine and subaerial erosion.

Coast-lines. The coast-line of India is comparatively uniform and regular, and is broken by few indentations of any magnitude For the greater part of its length a sandy and gently-shelving coast-strip is washed by a shallow sea The proportion of the sea-board to the mean length of the sides of the Peninsula is very small. The western sea-board has, however, a large number of shallow lagoons and back-waters all along its length, which constitute an important topographic feature of these coasts This coast is exposed to the action of the persistent south-west monsoon gales which blow from May to October, and is, therefore, subject to a more active erosion by the sea-waves than the east coast. The rapidity of the coastal erosion is, however, in some measure retarded by the gently shelving nature of the sandy shores, and also by the lagoons and back-waters, both of which factors help to break the fury of the waves. The coasts are fronted by a low submarine plain or platform where the sea is scarcely 100 fathoms deep. This "plain of marine denudation" is much broader on the western coast than on the eastern. On both the coasts there are "raised-beaches" or more or less level strips of coastal detritus, situated at a level higher than the level of highest tides. This is a proof of a slight recent elevation of the coasts.

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References to the physiographic features of India are scattered in numerous publications of the G S I., especially in the writings of Blanford, Medlicott, Oldham, Hayden and many other geologists.

CHAPTER XXVI

ECONOMIC GEOLOGY

IN the preceding chapters we have dealt with the stratigraphical and structural geology of India It is necessary for the student of Indian geology to acquaint himself with the various mineral products of the rock-systems of India and the economic resources they possess. In the following few pages we shall deal with the occurrence, the geological relations and some facts regarding the production of the most important of these products. For fuller details as well as for statistics, the student must refer to the excellent Quinquennial Reports of the Mineral Production of India, published by the Geological Survey of India[1] The subject is of the highest importance, and no little interest, for the student of Indian geology, and deserves his most careful attention. A knowledge of the mineral resources of India, while of great value to miners, engineers and architects for their own distinct avocations, has a most useful application in the commerce and industry, the arts and manufactures of the country.

For our purpose the various useful products which the rocks and minerals of India yield, can be classified under the following heads :

(1) Water.
(2) Clays, Sands.
(3) Lime, Cements, etc
(4) Building-Stones.
(5) Coal, Petroleum, etc.
(6) Metals and Ores.
(7) Precious and Semi-precious Stones
(8) Other Economic Minerals and Mineral Products.
(9) Soils.

[1] Also the instructive series of Bulletins of Indian Industries and Labour (Mineral series)

1. WATER

Besides its use for domestic and agricultural purposes, water has many important uses in manufacturing and engineering operations, and the geologist is often called upon to face problems regarding its sources and supply. Porous water-bearing strata exist everywhere among the old sedimentary formations as well as among recent alluvial deposits, but a knowledge of the geological structure is necessary in order to tap these sources with the maximum of efficiency. A large part of the rain that falls in India is speedily returned to the sea, only a very small percentage being allowed to soak underneath the ground This arises from the peculiar monsoonic conditions of its climate which crowds into a few months all the rainfall of the year, which rapidly courses down in flooded streams and rivers. The small percentage which is retained soaks down and saturates the strata to a certain level (*level of saturation*) and, after a variable amount of circulation underground, issues out again, on a suitable outlet being found, whether in the form of springs, wells or seepages. In India the great alluvial plains of the Indus and Ganges are a great reservoir of such stored-up water, and yield any quantity of sweet water by boring to suitable depths below the surface Wells, the most common source of water in India, are merely holes in the surface below the line of saturation, in which water accumulates by simple drainage or by percolation Springs are common in the rocky districts where pervious and impervious strata are interbedded and inclined or folded; or where a set of rocks is traversed by joints, fissures or faults. If a porous water-bearing stratum is enclosed between impervious strata above and below it, and bent into a trough, conditions arise for artesian wells when a boring is made reaching the water-bearing stratum. Such ideal conditions, however, are rarely realised actually, but there are some other ways by which less perfect artesian action is possible. The formation of an underground watertight reservoir, either by the embedding of tongues of gravel and sand under impervious alluvial clays, the abutting of inclined porous strata against

Wells

Springs.

Artesian wells.

impervious unfissured rocks by means of faults, or the intersecting of large fissures in crystalline rocks, gives rise to conditions by which water is held underground under a sufficient hydrostatic pressure to enable it to flow out when an artificial boring is made reaching the water. Artesian wells are not of common occurrence in India, nor are conditions requisite for their action often met with. The best known examples are those of Quetta along with the Karez already referred to (p 268) in the great gravel slopes (Daman) of Baluchistan. Artesian wells are sometimes possible in the alluvial districts of North India and in Gujarat,[1] by the imbedding of pockets of loose gravel or coarse sands in the ordinary alluvium. The introduction of artesian wells into the arid parts of this country, suffering from irregular or scanty rainfall, would be of great utility for the purposes of irrigation, but a knowledge of the geological structure of the district is essential before any costly experiment can be undertaken in borings

Mineral springs

Thermal [2] and mineral springs occur in many parts of India, especially in the mountainous districts like Sind, Assam, Salt-Range, in the foot-hills of the Himalayas, in Kashmir, etc Among them are sulphurous (which are the most common), saline, chalybeate, magnesian and other springs according to the principal mineral content of the waters. Several springs of radio-active waters are known. Many medicinal virtues are ascribed to such springs in Europe In India no such powers are recognised in them, and where, in a few cases, they are recognised, no economic benefit is derived from them. They are invested with religious sanctity rather than exploited for commercial gain.

[1] Instances of successful artesian borings in Gujerat are Navsari, Viramgam and Mahi. Artesian wells also exist in the alluvial tract in Rawalpindi and Pondicherry For additional information on artesian wells in India see Vredenburg's *Mem G S I.* vol. xxxii. pt. 1, 1901

[2] There are several thermal springs in the Karakpur hills One of these, the *Sitakund*, near Monghyr, is well known. At Gangotri, the source of the Ganges, there is another well-known spring of hot water. At the boiling springs of Manikarn (Kulu) people cook their food in the jets of issuing water *Tatta pani* in Poonch is a thermal sulphurous spring of large volume of discharge. Temp about 190° F,

2. CLAYS

China clay. Clay, that kind of earth which, when moistened, possesses a high degree of tenacity and plasticity, is of great industrial use in the making of various kinds of earthenware, tiles, pipes, bricks, etc., and when of sufficient purity and fine grain, it is of use in the manufacture of glazed pottery and high-grade porcelain, for all of which an immense demand exists in the modern world.[1] Pure china-clay, or kaolin, occurs in deposits of workable size among the Upper Gondwana rocks of the Rajmahal hills of Bengal and in Jabalpur. China clay, which has resulted from the decomposition of the felspar of the gneisses, occurs in some aggregates in some districts of Madras.

Terra cotta. China clay, which is somewhat impure and coloured buff or brown, is known as *terra-cotta*, which finds employment in the making of unglazed large-size pottery, statuettes, etc, and to some extent for architectural purposes. Terra-cotta clay deposits are of more common occurrence in India and Burma than pure kaolin The kaolin (pure china clay) deposits of the Rajmahal hills at Colgong (Pattarghatta) are of much interest, both as regards the quantity available and the purity of the material, for the manufacture of very superior grades of porcelain.[2] Similar deposits, though on a more restricted scale, are found in Bhagalpur and in Gaya.

Fire-clay. Fire-clay is clay from which most of the iron and salts of potassium and sodium are removed, and which, therefore, can stand the heat of furnaces without fusing Fire-clay from which fire-bricks of high refractory quality can be manufactured occurs in beds at the western side of the Rajmahal hills. It also occurs as underclays in the Gondwana coal-measures and associated with other coal-bearing series Besides these localities, fire-clay of texture and refractoriness suitable for the manufacture of furnace-bricks is obtained from a number of localities in the Central Provinces, Bengal, etc., where its deposits are of fairly wide distribution.

Fuller's earth. Fuller's earth is a kind of white, grey or yellow coloured clay It has a high absorbent power for many substances,

[1] *Clays, their Occurrence, Properties and Uses*, H. Ries, 1906

[2] M. Stuart, *Rec. G.S I.* vol, xxxviii. pt. 2, 1909,

ʼhich reason it is used for washing and cleaning purposes found, among many other places, in the Lower Vindhyan ꞉ of Jabalpur district (Katni). It is also obtained from Eocene rocks of Jaisalmer and Bikaner in Rajputana, e it is quarried and sold under the name of *Multani* ꞉e

dinary alluvial clay, mixed with sand and containing a in proportion of iron, is used for brick-making and crude en pottery. Fine-grained clay, mixed with fine sand, ed in tile-making Mangalore, together with some surling places, is the home of a flourishing tile industry, e tiles of all sorts and suitable for paving, roofing and g are manufactured.

SANDS

ʼe quartz-sand, free from all iron impurities and possessuniform grain and texture, is of economic value in the facture of glass Such sands are rare in India, but in ; years good sands have been obtained from pure quartzose iyan sandstones at several localities in the United Pro- ꞉ and from Cretaceous sandstones found in the Baroda Ordinary white sand is used in India for the manu- ʼe of inferior varieties of glass, while articles of better y are manufactured out of crushed quartz at Talegaon a), Jabalpur, and at Ambala, Allahabad and Madras. **Glass-sand**

imon river sands are used in mortar-making Recent eous sands, consisting mostly of shells of foraminifera, consolidated into a kind of coarsely-bedded freestone ie places on the west coast of the Arabian Sea—Miliolite. Iagnetite sand, Monazite sand, Gem sand, etc.)[1]

3. LIME, CEMENTS, Etc.

e for mortar-making is obtained by burning limestone, iich most kinds of limestones occurring in the various ical systems of India are suitable, but some are especially ɔr the purpose Lime, when mixed with water and sand, ꞉d mortar, which, when its loses its water and absorbs **Mortar**

[1] *ls and Crushed Rocks,* A B. Searle, Oxford Technical Publications

carbonic acid gas from air, "sets" or hardens, hence its use as a binding or cementing material. In the plains of India, the only available source of lime is "Kankar," which occurs plentifully as irregular concretions disseminated in the clays. The clay admixture in Kankar is often in sufficient proportion to produce on burning a hydraulic lime. Travertine or calc-tufa, sea-shells, recent coral limestones, etc., are also drawn upon for the kiln, where a suitable source of these exists When limestone containing argillaceous matter in a certain pro-

Cement

portion is burnt, the resulting product is *cement*, in which an altogether different chemical action takes place when mixed with water The burning of limestone ($CaCO_3$) and clay (Al_2O_3, SiO_2, nH_2O) together results in the formation of a new chemical compound—silicate and aluminate of lime—which is again acted upon chemically when water is added, hardening it into a dense compact mass For cement-making, either some suitable clayey limestone is used or the two ingredients, limestone and clay, are artificially mixed together in proper proportion. The former is known as Roman Cement, the latter as Portland Cement The occurrence of enormous masses of pure nummulitic and other limestones in the Punjab, in association with clays and shales, offers favourable conditions for cement manufacture in that province Natural cement-stones of suitable composition exist in some parts of India Kankar also may be regarded as one of them

There are a few centres for lime and cement production in India on an industrial scale; the chief of these are. Katni, near Jabalpur, which derives its raw material from the Lower Vindhyan series; Sutna, in the Rewa State, which has its supply from the Upper Vindhyan; Sylhet, from the nummulitic limestone of the Assam range; Gangpur, in Bengal, which derives its material partly from the Vindhyan limestones and partly from Kankar The cement works of the Shahabad district, Bengal, also obtain their limestone from the Vindhyan (Rohtas) limestone. Materials for cement manufacture are found in the Punjab in the Rewari district, parts of the Salt-Range, Hazara, Outer Himalayas, etc.

4. BUILDING-STONES

Rocks are quarried largely for use as building-stones.[1] Not all rocks, however, are suitable for this purpose, since several indispensable qualities are required in a building-stone which are satisfied by but a few of the rocks from among the geological formations of a country. Rocks that can stand the ravages of time and weather, those that possess the requisite strength, an attractive colour and appearance, and those that can receive dressing—whether ordinary or ornamental—without much cost or labour, are the most valuable. Susceptibility to weather is an important factor, and very costly experiments have been made to judge of the merits of a particular stone in this respect.

With this view the architects of new Delhi, who require a most extensive range of materials for a variety of purposes, building as well as architectural, invited the opinion of the Geological Survey of India in regard to the suitability of the various building and ornamental stones quarried in the neighbouring areas of Rajputana and Central India. A special officer of the Survey was deputed to advise on the matter after an examination of the various quarries that are being worked in these provinces.

In northern India, the ready accessibility of brick-making materials in unlimited quantities has rendered the use of stone in private as well as public buildings subordinate. Excellent material, however, exists, and in quantities sufficient for any demand, in a number of the rock-systems of the country, whose resources in rocks like granites, marbles, limestones and sandstones are scarcely utilised to their full extent. An enumeration of even the chief and the more used varieties of these would form a catalogue too long for our purpose.

Granites.

Granite, or what passes by that name, coarsely foliated gneiss, forms very desirable building-stones, very durable and of an ornamental nature. These rocks, by reason of their massive nature and homogeneous grain, are eminently adapted for monumental and architectural work as well as for massive

[1] *Stones for Building and Decoration*, G. P. Merrill, 1910.

masonries Its wide range in colour and appearance—white, pink, red, grey, black, etc —renders the stone highly ornamental and effective for a variety of decorative uses. The charnockites of Madras, the Arcot gneiss, Bangalore gneiss, the porphyries of Seringapatam, and many other varieties of granite obtained from the various districts of the Peninsula are very attractive examples Its durability is such that the numerous ancient temples and monuments of South India, built of granite, stand to-day almost intact after centuries of wear, and to all appearance are yet good for centuries to come From their wide prevalence, forming nearly three-fourths of the surface of the Peninsula, the Archaean gneisses form an inexhaustible source of good building and architectural material.[1]

Limestones. Limestones occur in many formations, some of which are entirely composed of them. All of them, however, are not fit for building purposes, though many of them are burnt for lime In the Cuddapah, Bijawar and Aravalli groups limestones attain considerable development, some of them of great beauty and strength. They have been largely drawn upon in the construction of many of the noted monuments of the past in all parts of India Vindhyan limestones are extensively quarried, as already referred to, in Central India and elsewhere, and form a valued source for lime and cement, as well as building-stone. The Gondwanas are barren of calcareous rocks, but the small exposures of the Bagh and Trichinopoly Cretaceous include excellent limestones, sometimes even of an ornamental description. The nummulitic limestones of the extra-Peninsular districts are an enormous repository of pure limestone, and when accessible are in great requisition for burning, building, as well as road-making purposes.

Marbles. The marble-deposits of India are fairly wide-spread and of large extent The principal source of the marbles of

[1] In connection with the building of the Alexandra docks at Bombay, a series of tests on Indian granites was undertaken. These have proved that the granites from South Indian quarries are equal to or better than Aberdeen, Cornish or Norwegian granites in respect of compressive strength, resistance to abrasion, absorption of water, and freedom from voids The verdict of the various experts consulted was altogether favourable to the use of Indian granites for purposes for which imported granites alone were considered suitable. ("Indian Granites," *Bombay Port Trust Papers*, 1905.)

ia is the crystalline formation of Rajputana—the Aravalli
es. Marble quarries are worked at Mekrana (Jodhpur),
arwa (Ajmer), Maundla and Bhainslana (Jaipur), Dadikar
war), and some other places, from which marbles of
ny varieties of colour and grain, including the beautiful
ite white variety of which the Taj Mahal is built, are
ined. It was the accessibility of this store of material of
irpassed beauty which, no doubt, gave such a stimulus
the Mogul taste for architecture in the seventeenth
ury.

saccharoidal dolomitic marble occurs in a large outcrop
· Jabalpur, where it is traversed by the Narbada gorge.
famous quarries of Mekrana supply white, grey and pink
bles; a handsome pink marble comes from Narbada in
Kishengarh State Jaisalmer in Rajputana supplies a
ow shelly marble, while a lovely green and mottled marble
nsurpassable beauty is obtained from Motipura, from an
sure of the Aravalli rocks in the Baroda State. A mottled
or pink marble is found in the same locality and also in
or two places in the Aravalli series of Rajputana and of the
ingpur district of the Central Provinces. The Kharwa
ries of Ajmere produce green and yellow-coloured marbles.
k or dark-coloured marbles come from Mekrana and from
Kishengarh State, though their occurrence is on a more
ed scale than the lighter varieties. A dense black marble,
ble of taking an exquisite polish, largely employed in the
nt buildings of Delhi, Agra and Kashmir, with highly
nental effect, is furnished by some quarries in the Jaipur
Coarse-grained marbles are more suitable for archi-
ral and monumental uses; it is the coarseness of the
which is the cause of the great durability of marble
st meteoric weathering. The fine-grained, purest,
marbles are reserved for statuary use, for which no
varieties can be of service.

s a most regrettable fact, however, that the above-noted
its of Indian marbles do not find any market to encour-
heir systematic quarrying. There is no considerable
nd for indigenous marbles in India, nor do facilities
for their export to foreign countries. The deposits,

therefore, have to wait the demand of a more thriving and more aesthetic population in the future

A fine collection of Indian marbles, representing the principal varieties, is to be seen in the Indian Museum, Calcutta.

Serpentine.

Serpentine forms large deposits in the Arakan range of Burma and also in Baluchistan. It occurs as an alteration-product of the basic and ultra-basic intrusions of Cretaceous and Miocene ages. From its softness and liability to weather on exposure it is of no use for outdoor architectural purposes, but serpentines of attractive colour are employed in internal decorations of buildings, and the manufacture of vases, statuary, etc. Serpentinous marble (*Verde antique*) is rare in India.

Sandstones.

Vindhyan sandstones.

The Vindhyan and, to a lesser extent, the Gondwana formations afford sandstones admirably suited for building works The most pre-eminent among them are the Upper Vindhyan sandstones, which have been put to an almost inconceivable number of uses From the rude stone-knives and scrapers of the palaeolithic man to the railway telegraph boards, and the exquisitely-carved monoliths of his present-day successor, these sandstones have supplied for man's service an infinity of uses. It is the most widely quarried stone in India, and being both a freestone as well as a flag-stone, it can yield, according to the portion selected, both gigantic blocks for pillars from one part, and thin, slate-like slabs for paving and roofing from another part.

Dr. V. Ball,[1] in writing about Vindhyan sandstones, says, "The difficulty in writing of the uses to which these rocks have been put is not in finding examples, but in selecting from the numerous ancient and modern buildings which crowd the cities of the United Provinces, and the Ganges valley generally, and in which the stone-cutter's art is seen in the highest perfection." Some of the Vindhyan sand-stones are so homogeneous and soft that they are capable of receiving a most elaborate carving and filigree work

Gondwana sandstones.

Another formation possessing resources in building-stones of good quality is the Upper Gondwana, which has contributed a great store of building-stone to Orissa and Chanda. The

[1] *Geology of India*, vol iii 1881.

mous temples of Puri and the other richly ornamented uldings of these districts are constructed of Upper Gondwana ndstones.

The Jurassic (Umia) sandstone of Dhrangadhra and the etaceous sandstone underlying the Bagh beds of Gujarat ongir sandstones) furnish Gujarat with a very handsome and urable stone for its important public and private buildings.

Among the Tertiary sandstones, a few possess the qualities quisite in a building-stone, e g the Murree and Kamlial 'arki) sandstones , but the younger Siwalik sandstones are o unconsolidated and incoherent to be fit for employment building work.

Quartzites, laterites, etc. Quartzites are too hard to work and have a fracture and ain unsuitable for dressing into blocks.

Laterites of South India are put to use in building-works, om the facility with which they are cut into bricks or ocks when freshly quarried

Slates. Slates for paving and roofing are not of common occurrence India, except in some mountainous areas, e g at Kangra and r Panjal in the Himalayas and Rewari in the Aravallis. hen the cleavage is finely developed and regular, thus enabg them to be split into thin even plates, the slates are used for ofing , when the cleavage is not so fine, the slates are used for ving. True cleavage-slates are rare in India , what genery are called slates are either phyllites or compacted shales which the planes of splitting are not cleavage-planes.

The chief slate-quarries of India are those of Kangra, in the angra district ; Rewari, in the Gurgaon district ; and harakpur hills, in the Monghyr district.

Traps. Besides the foregoing examples of the building-stones of dia, a few other varieties are also employed as such when adily available and where a sufficient quantity exists. Of ese the most important are the basalts of the Deccan, which, om their prevalence over a wide region of Western India, e used by the Railways and Public Works Department for eir buildings, bridges, the permanent way, etc. The traps rnish an easily workable and durable stone of great strength, t its dull, subdued colour does not recommend it to popular vour.

5. COAL[1]

Production of coal in India.

Coal is the most important of the mineral products raised in India. Within the last thirty years India has become an important coal-producing country, the annual production now nearly supplying her own internal consumption The yearly output from the Indian mines has risen to over 19,000,000 tons, valued at Rs 145,000,000. Of this output, by far the largest portion—89 5 %—is derived from the coal-fields of Bengal, Bihar and Orissa; about 3 5 % from the Singareni field of the Haiderabad State, about 3 5 % from the Central Provinces mines, and 1 % from the Umaria field of Central India. This gives a total of 97 5 % for the production of coal from the Peninsula. In its geological relations the coal of the Peninsula is entirely restricted to the Damuda series of the Lower Gondwana system The remainder of the coal raised in India comes from the Lower Tertiary, Eocene, or Miocene rocks of the extra-Peninsula, viz. Assam (Makum), Salt-Range (Dandot), Baluchistan (Khost) and Bikaner (Palana). Of these, the Assam production is the most important and promising for the future, it averages nearly 2 % of the total Indian produce, while it also approaches Gondwana coal in its quality as a fuel

The following table shows the relative importance of the various coal-fields of India, with their yearly output in round numbers.

Gondwana Coal

Bengal, Behar, and Orissa.	Tons
1 Raniganj	5,000,000
2. Jherria	10,000,000
3. Giridih	800,000
4. Bokaro	1,000,000
Central India	
1. Umaria	150,000

[1] "The Coalfields of India," *Mem G S I* vol xli. pt 1, 1913.

Central Provinces	Tons.
1. Bellarpur - - - - - - -	150,000
2. Pench Valley - - - - - -	450,000
3. Mohpani - - - - - - -	88,000
Haiderabad	
1 Singareni - - - - - - -	630,000

Tertiary Coal.

1 Assam (Makum) - - - - -	300,000
2 Baluchistan (Khost) - - - - -	33,000
3 Salt-Range (Dandot) - - - -	50,000
4 Bikaner (Palana) - - - - -	18,000

Three New Gondwana coal-fields are being opened and are at present under rapid development Ramgarh (40 sq. miles), Karanpura (475 sq. miles) and Talchir (8 sq. miles). Large reserves of coal have been proved in these new fields.

Coal in workable quantity exists in the Korea State,[1] Central Provinces. Some widely distributed, though thin, Tertiary coal-seams have been proved in the Riasi district of Jammu [2]

In general, the Gondwana coal is a laminated bituminous coal in which dull and bright layers alternate. Anthracite, i e coal in which the percentage of carbon is more than 90, and from which the volatile compounds are totally eliminated, is not found in India. The volatile compounds and ash are, as a rule, present in too large a proportion to allow the carbon percentage to rise above 55 to 60, generally much less than that Moisture is absent from the coal of the Gondwana fields, but sulphur and phosphorus are present in variable quantities in the coals of the different parts of the Peninsula.

It is probable that a large extent of coal-bearing Gondwana rocks lies hidden underneath the great pile of lavas of the Deccan trap At several places, chiefly in the Satpuras, the denudation of the latter have exposed coal-bearing Gondwana strata, from which it is reasonable to infer that considerable quantities of the valuable fuel are buried under the formation in this and more westerly parts. Of the coal of younger age, worked from the extra-Peninsula, Assam coal is of a high grade

[1] Fermor, *Mem. G S.I.* vol. xli pt. 2, 1914

[2] Simpson, *Mem. G.S.I* vol. xxxii. pt. 2, 1904.

as fuel, while that of the Punjab has a lower percentage of fixed carbon. In the former it rises to as much as 53 %, in the latter it never goes beyond 40 % The latter coal, properly a lignite, is more bituminous, friable and pyritous, and contains much moisture. The two last qualities make it liable to disintegration on exposure, and even to spontaneous combustion. With regard to its geological relations, the extra-Peninsular coal is principally restricted to the Laki horizon, at the base of the Kirthar or Nummulitic limestone series, though some of the richest coal-seams of Assam belong to strata of younger age (Miocene). The Tertiary coal of Palana (Bikaner) is, properly speaking, a lignite (brown coal), though belonging to the same geological horizon as the coal of the Salt-Range A small quantity of the coal of Assam is of Cretaceous age, while a few thin seams of brown coal occur in the Jurassic strata of Cutch, and also in the Mianwali district (Kalabagh)

The hitherto coal-less area of Kashmir has lately been found to possess fuel deposits of considerable size, belonging to Pliocene or even newer age Thin seams of brown coal or lignite occur interstratified with the top beds of the older Karewa series within a few feet from the surface Over a hundred million tons of moderate-grade lignite is easily recoverable from one area. The percentage of combustible matter is generally about 55 [1]

PEAT

The occurrence of peat in India is confined to a few places of high elevation above the sea True peat is found on the Nilgiri mountains in a few peat-bogs lying in depressions composed of the remains of Bryophyta (mosses). In the delta of the Ganges, there are a few layers of peat composed of forest vegetation and rice plants In the numerous *Jhils* of this delta peat is in process of formation at the present day and is used as a manure by the people. Peat also occurs in the Kashmir valley in a few patches in the alluvium of the Jhelum, it is there composed of the débris of several kinds of aquatic vegetation, grasses, sedges and rushes. Similar deposits of peat are in course of formation in the valley of Nepal The chief use of peat is as a fuel, after cutting and drying It is also employed as a manure.

[1] C S Middlemiss, *Rec G S I* vol lv pt 3, 1924.

PETROLEUM

Occurrence in Burma and Assam.

The occurrence of petroleum in India is restricted to the extra-Peninsula, where a petroliferous horizon occurs in the Pegu series of Middle Tertiary age in Burma and Assam on the east and the northern districts of the Punjab and Baluchistan on the west. In Burma [1] there is a series of low, broad anticlines or domes of porous oil-bearing strata of sand interbedded with impervious clays which have given rise to the most perfect conditions for the underground storing of oil. The most productive oil-fields of Burma are those situated in the Irrawaddy basin, along a belt stretching from the Magwe district to Pakokku The most important of these fields are. the Yenangyaung, in the Magwe district, which yields nearly 180,000,000 gallons a year; Singu, in the Myingam district, 100,000,000 gallons, Yenangyat, Pakokku district, 2,000,000 gallons, Minbu, district of Minbu, 3,900,000 gallons. The other province in India that produces petroleum on a commercial scale is Assam. The oil resources of Assam are centred in the Lakhimpur district where an important petroleum-bearing horizon occurs associated with the Miocene coal-measures of Makum. Digboi is the chief centre. The annual yield has, in recent years, come up to 7,500,000 gallons. The other field, Badarpur, produced 4,000,000 gallons in 1923

Oil-springs have been known to exist in the Rawalpindi, Attock, and other Frontier Provinces, and late investigations in this area have shown that a narrow zone of Middle Eocene strata (base of the Chharat series) is the source of oil and bitumen which has, by upward migration, saturated the newer Murree sandstones. Conditions, both as regards the geological structure and storage of petroleum, appear to be favourable in this region; but so far, in spite of very energetic prospecting of large areas, only one field is in successful operation (the Khaur field, Attock district) of which the output in 1923 was 11,800,000 gallons [2]

In the refining of crude petroleum, *i.e* the oil as obtained from the oil-springs or wells, various kinds of oils and greases are produced, together with a chain of bye-products of high commercial utility, *e g.* petrol, benzene, fuel-oils, lubricating oils, kerosene and other illuminating oils, grease, paraffin-wax (for candles), vaseline, and a number of other minor products.

[1] Pascoe, "The Oil-fields of Burma," *Mem G S I* vol xl. pt 1, 1911.

[2] E S Pinfold, "Occurrence of Oil in the Punjab," *Jour Asiat. Soc. Beng.* (New Sers), vol. xiv 1918

Natural gas.

Natural gas (chiefly marsh gas with some other gaseous hydro-carbons) is present in enormous volume associated with the petroleum deposits, and escapes with great force when a boring is made Natural gas has no industrial application in India, but in other countries it is stored and is piped to long distances for use as fuel in factories and for heating and lighting purposes in cities.[1]

6. METALS AND ORES

General.

India contains ores of manganese, iron, gold, aluminium, lead, copper, tungsten, tin, chromium, and a few other metals in minor quantities, associated with the crystalline and older rocks of the country In the majority of the cases, however, the ore bodies are worked, not for the extraction of the metals contained in them, but for the purpose of exporting the ores as such in the raw condition, since no smelting or metallurgical operations are carried on in the country at the present time For this reason the economic value of the ores realised by the Indian miners is barely half the real market-value, because of the heavy cost of transport they have to bear in supplying ores to the European manufacturer at rates current in the latter's country. The absence of metallurgical enterprise in this country at the present day has led to a total neglect of its ore-deposits, except only those whose export in the raw condition is paying. This is a serious drawback in the development of the mineral resources of India, the cause for which lies in the present imperfect and undeveloped state of the country's industries Sir T H Holland, in his review of the mineral production of India, pointed out in 1908 that the "principal reason for the neglect of the metalliferous minerals is the fact that in modern metallurgical and chemical developments the bye-product has come to be a serious and indispensable item in the sources of profit, and the failure to use the bye-product necessarily involves neglect of minerals that will not pay to work for the metal alone Copper-sulphide ores

Neglect of ore-bodies in India.

[1] E H Pascoe, "Oil Fields of Burma, Assam and Punjab," *Mem G.S I.* vol xl. pts. 1, 2 and 3, 1911-20

are conspicuous examples of the kind; many of the most profitable copper mines of the world would not be worked but for the demand for sulphuric acid manufacture, and for sulphuric acid there would be no demand but for a string of other chemical industries in which it is used. A country like India must be content, therefore, to pay the tax of imports until industries arise demanding a sufficient number of chemical products to complete an economic cycle, for chemical and metallurgical industries are essentially gregarious in their habits." Many of the ore-deposits of India, although of no economic value under the conditions prevailing at the present day, are likely to become so at a future day when improved methods of treatment and better industrial conditions of the country may render the extraction of the metals more profitable. From this consideration the large yearly exports of such ores as manganese out of India are doubly harmful to the interests of the country.

Gold.

Occurrence.

Gold occurs in India, both as native gold, associated with quartz-veins or reefs, and as alluvial or detrital gold in the sands and gravels of a large number of rivers. The principal sources of the precious metal in India, however, are the quartz-reefs traversing the Dharwar rocks of Kolar district (Mysore State), which are auriferous at a few places.[1] The auriferous lodes of the Kolar goldfields are contained in the above-mentioned quartz-veins, which run parallel to one another in a north-south direction in a belt of hornblende-schists. The most productive of these is a single quartz-vein, about four feet thick, which bears gold in minute particles. The gold is obtained by crushing and milling the quartz, allowing the crushed ore mixed with water to run over mercury-plated copper boards. The greatest part of the gold is thus dissolved by amalgamation. The small residue that has escaped with the slime is extracted by the cyanide process of dissolving gold.

Production of vein-gold.

The annual yield of gold from the Kolar fields is nearly 560,000 ozs., valued at more than £2,000,000. Next to Kolar,

[1] "Kolar Gold-Field," *Mem. G.S.I.* vol. xxxiii. pt. 1, 1901.

but far below it in productiveness, is the Hutti gold-field of the Nizam's dominions, which is also worked from a similar outcrop of Dharwar schists It produced 21,000 ozs. of gold in 1914. A few quartz-veins traversing a band of chloritic and argillaceous schists, also of Dharwar age, support the Anantpur field of Madras, whose yield in 1915 approached 24,000 ozs At some other places in the Peninsula, besides those named above, the former existence of gold is revealed by many signs of ancient gold-working in diggings, heaps of crushed quartz, and stone-mortars, which have (as has often happened in India with regard to other metalliferous deposits) guided the attention of the present workers to the existence of gold

Alluvial gold. The distribution of alluvial gold in India is much wider. Many of the rivers draining the crystalline and metamorphic tracts in India and Burma are reputed to have auriferous sands, but only a few of them contain gold in a sufficient quantity to pay any commercial attempt for its extraction. The only instance of successful exploitation of this kind is the dredging of the upper Irrawaddy valley for the gold-bearing gravel at its bed. In this way some 5000 to 6000 ozs of gold is won a year. Alluvial gold-washing is carried on in the sands and gravels of many of the rivers of the Central Provinces, and in the Indus valley at Ladakh, Baltistan, Attock, etc , but none of them are of any richness comparable to the above instance. The quantity won by the indigent workers is just enough to give them their day's wages.

Copper.

Occurrence. Copper occurs in some districts of India—Singhbhum, Chota Nagpur, etc.; in Rajputana—Ajmere, Khetri, Alwar, Udaipur, and at several places in the Outer Himalayas, in Sikkim, Kulu, Gharwal, etc. But the only deposits worked with some degree of success are those of the Singhbhum district, which yield about 30,000 tons per year, valued at from £20,000 to £32,000. In Singhbhum the copper-bearing belt of rocks is persistent for about 80 miles. The deposits worked by the Rakha Mines consist of low-grade sulphide ore assaying 2–4 % of copper Somewhat richer ore-shoots have

located lately by other mines. There was a flourishing ›nous copper-industry in India in former years, producing quantities of copper and bronze from the Rajputana and bhum mines, the sites of which are indicated by extensive ıeaps and refuse "copper-workings." Important copper- ; existed in Ajmere and in Khetri (in the Jaipur State) n historic times.

e copper ores of Singhbhum and Rajputana occur as veins disseminations in the Dharwar schists and phyllites. In ıt number of cases, however, the ore occurs in too scattered dition to be worth working, it is only rarely that local ntration has produced workable lodes or veins. The common ore is the sulphide, chalcopyrite, which by ce-alteration passes into malachite, azurite, cuprite, etc. tive copper occurs at some places in South India. In mir large isolated masses of pure native copper have found in the bed of the Zanskar river, but their source ıknown. They occur there as water-worn nodules, ıng up to 22 lbs.

Copper ores of Sikkim.

e copper deposits of Sikkim attracted much attention [1] In this State valuable lodes of the metal are proved ıst in association with compounds of bismuth and anti-, together with ores like pyrrhotite, blende and galena. regard to the geological relation and mode of origin, the m deposits are similar to those of Singhbhum. The ɜr are also associated with schists and gneiss of the Daling ı, which are the Himalayan representatives of Dharwars. ɔth cases again the mode of origin of the ore bodies is ame, viz. they have resulted from the metasomatic re-ment of the country-rock by copper-bearing solutions ed from granite and other intrusions associated with the war rocks of South India or the Dalings of Sikkim.

Occurrence

n occurs on a large scale in India, chiefly in the form of xides · haematite and magnetite. It prevails especially e Peninsula, where the crystalline and schistose rocks of)harwar and Cuddapah systems enclose at some places

[1] H. H. Hayden, *Rec. G.S.I.* vol xxxi. pt. 1, 1904.

ferruginous deposits of an extraordinary magnitude. Among these, massive outcrops of magnetite and haematite of the dimensions of whole hills are not unknown. But the most common mode of occurrence of iron is as haematite-and-magnetite-quartz-schists, the metamorphosed products of original ferruginous sands and clays. The high grade haematitic ore-bodies of Singhbhum, together with those of Keonjhar, Bonai and Mayurbhanj, discovered of late, are believed to be of Upper Dharwar age, the remarkable concentration of the metal iron in them being ascribed to post-Cuddapah metasomatic action. These ore-bodies are thought to be the largest and richest deposits of iron perhaps in the world, surpassing in magnitude the Lake Superior ores They are estimated to contain about three thousand million tons of metallic iron.[1]

The Damuda series of Bengal holds valuable deposits of bedded or precipitated iron ore in the ironstone shales. Some iron ore is enclosed in the Upper Gondwana haematitic shales. The Deccan Traps, on weathering, liberate large concentrates of magnetite sands on long stretches of the sea-coast. Iron is a prominent constituent of laterite, and in some varieties the concentration of limonite or haematite has reached so high that the rock is smelted for iron. In the Himalayas, likewise, there occur large local deposits of this metal in the Purana formations.

Economic value

The only deposits that are profitably worked at the present day are the ironstone shales of Burdwan, the high-grade ores of Mayurbhanj, Singhbhum and Manbhum, and to a less extent those of Bababudan hills, Mysore State, and the Central Provinces. The aggregate produce of iron in 1924 reached 600,000 tons of pig-iron and 200,000 tons of steel.

Iron seems to have been worked on an extensive scale in the past, as is evident from the widely scattered slag-heaps which are to be seen in almost every part of South India. The iron extracted was of high quality and was in much demand in distant parts of the world. The fame of the ancient Indian steel, *Wootz*—a very superior kind of steel exported to Europe, in days before the Christian era, for the

[1] H C Jones, *Rec. G S I.* vol. liii. pt. 3, 1922.

nufacture of swords and other weapons—testifies to the tallurgical skill of the early workers

Every year India imports iron and steel materials (hard-re, machinery, railway plant, bars and sheets, etc) to the ue of nearly £26,000,000.

A list of localities which contain the most noted deposits of 1 ore will be interesting

Distribution

n the Madras Presidency the most important deposits are se of Salem, Madura, Mysore (Bababudan hills), Cuddapah Karnul, while Singhbhum, Manbhum, Burdwan, Sambalpur Mayurbhanj are the iron-producing districts of Bengal, iar and Orissa In Bengal proper, the Damuda ironstone les contain a great store of metallic wealth, which has n profitably worked for a long time, both on account of intrinsic richness as well as for its nearness to the chief rce of fuel In Assam also iron occurs with coal. In the tral Provinces the most remarkable iron deposit is that he Chanda district, where there is a hill 250 feet high, indeshwar by name, the entire body of which is iron ore. alpur and Bhilaspur have likewise large aggregates In ibay the chief source of iron is laterite and the magnetite-ls of rivers draining the trap districts, both of which are ely drawn upon by the itinerant *lohars.* In the Himalayas Kumaon region has been known to possess some deposits. kable iron-ore is met with in the Riasi district, Jammu

ganese.

ith the exception of Russia (the Caucasus), India is the st producer of manganese in the world. Within the last ty years, the export of manganese ore has risen from a thousand tons to between 600,000 and 800,000 tons ally The major part of this output is exported in the ore ition, only a small part of it being treated in the country he production of the metal, or for its manufacture into -manganese, the principal alloy of manganese and iron.

Production of manganese in India.

e chief centres of manganese mining, or rather quarrying he method of extraction up till now resorted to is one of quarrying from the hillsides), are the Balaghat, Bhandara,

Distribution.

Chhindwara, Jabalpur and Nagpur districts of the Central Provinces, which yield nearly 60 per cent. of the total Indian output. Sandur and Vizagapatam in Madras take the next place, then comes the Panch Mahal district of Bombay, and Gangpur in Orissa, Chitaldrug and Shimoga districts of Mysore, and Jhalna in Central India.

Geographical.

Geological.

Dr Fermor has shown that manganese is distributed, in greater or less proportion, in almost all the geological systems of India, from the Archaean to the Pleistocene, but the formation which may be regarded as the principal carrier of these deposits is the Dharwar. The richly manganiferous facies of this system—the *Gondite* and *Kodurite series*—contain enormous aggregates of manganese ores such as psilomelane and braunite, pyrolusite, hollandite, etc. Of these the first two form nearly 90 per cent of the ore masses The geological relation of the ore bodies contained in these series and their original constitution have been referred to in the chapter on the Dharwar system (p 60). Besides the Dharwar system, workable manganese deposits are contained in the laterite-like rock of various parts of the Peninsula, where the ordinary Dharwar rocks have been metasomatically replaced by underground water containing manganese solutions. According to the mode of origin, the two first-named occurrences belong to the *syngenetic* type of ore bodies, *i.e.* those which were formed contemporaneously with the enclosing rock, while the last belong to the *epigenetic* class of ores, *i.e.* those formed by a process of concentration at a later date.

A voluminous memoir on the manganese-ore deposits of India by Dr. L L Fermor is published by the Geological Survey of India,[1] containing valuable information on the mineralogy, economics and the geological relations of the manganese of India.

Ores which contain from 40 to 60 per cent. of manganese are common and are known as *manganese ores*. There also exist ores with an admixture of iron of from 10 to 30 per cent · these are designated *ferruginous manganese ores*; while those which have a still greater proportion of iron in them are known as *manganiferous iron ores* The average cost of

[1] *Mem. G.S.I.* vol xxxvii 1909.

ın manganese ore delivered in London is less than Rs 30 ›on of first grade ore, *i e.* with a manganese percentage er than 50.

e chief use of manganese is in metallurgy for the manu- re of ferro-manganese and spiegeleisen, both of which ılloys of manganese and iron. Manganese is employed ›eral chemical industries as an oxidiser, as in the manu- re of bleaching powder, disinfectants, preparation of , etc. Manganese is employed in the preparation of ring materials for glass, pottery-paints, etc. The pink ›al, rhodonite (silicate of manganese), is sometimes cut ›ms on account of its attractive colour and appearance.

Uses.

ıinium.

Bauxite in laterite.

ce the discovery that much of the clayey portion of ›e is not clay (hydrated silicate of alumina), but the e hydrate of alumina (bauxite), much attention has been ed to the possibility of working the latter as an ore of nium.[1] Bauxite is a widely spread mineral in the ›e cap of the Peninsula, but the laterites richest in te are those of the Central Provinces, especially of (Jabalpur), and of some hill-tops in the Balaghat ›t in which the percentage of alumina is more than 50. important deposits are those of Mandla, Seoni, Kala- , Sarguja, Mahabaleshwar, Bhopal and the Palni hills ›me parts of Madras

›ensive deposits of bauxite have been discovered in ation with the Nummulitics of Jammu and Poonch. mode of occurrence also suggest a lateritic origin, *e g* by lication of large, subaerially exposed, spreads of infra- ıulitic clay-beds on a series of low, gently inclined ›pes.

Uses.

minium has a variety of applications in the modern ries It is esteemed on account of its low density, its y and malleability. Besides its use for utensils, it has applications in electricity, metallurgy, aeronautics, etc.

[1] . Fox, "Aluminous Laterites," *Mem G.S.I* vol. xlix.; "Bauxite ›es of India," *Mining Magazine*, vol. xxvi. Feb. 1922 Coggin *Bulletin of I. I. and L.* No. 2, 1921, No. 12, 1921.

It is largely employed in the manufacture of alloys with nickel, copper, zinc and magnesium. The present output of bauxite is insignificant and is chiefly consumed in the cement-making industry of Katni.

Lead, Silver, Zinc.

Very little lead is produced in India at the present time, though ores of lead, chiefly galena, occur at a number of places in the Himalayas, Madras and Bengal, enclosed either among the crystalline schists or, as veins and pockets, in the Vindhyan limestones. Lead was formerly produced in India on a large scale. The lead ores of Hazaribagh, Manbhum and some districts of the Central Provinces are on a fairly large scale, and they are often argentiferous, yielding a few ounces of silver per ton of lead But all of these are lying unworked; their remunerative mining is impossible because of the cheap price of imported lead.

Lead ores of Bawdwin

The only locality where a successful lead industry[1] exists is Bawdwin in the Northern Shan States of Upper Burma, where deposits of argentiferous galena occur on an extensive scale in a zone of highly fractured volcanic and metamorphosed rocks of Cambrian age[2] Large reserves of lead, zinc and silver ores have been proved in these mines and are under energetic exploitation. The country-rocks are felspathic grits and rhyolitic tuffs, the felspars of which are replaced by galena. Blende and copper-pyrites are associated with the lead-ores, together with their alteration-products in the zone of weathering—cerussite, anglesite, smithsonite, and malachite.

Up to this time the Bawdwin lead has been worked more from the heaps of slags left by the old Chinese workers of these mines than from the ores mined from deposits *in situ*. The annual production now reaches 40,000 tons of metallic lead

The Bawdwin ores belong, geologically, to the class of metasomatic replacements, the original minerals of the country-rock having been substituted chemically by the

[1] Coggin Brown, *Bull. I. I and L* No. 19, 1922.

[2] *Rec. G.S I.* vol. xxxvii. pt 3, 1909.

ıides and carbonates of lead and zınc, by the process of cular replacement.

dıa is the largest consumer of sılver in the world, the ıt of ıts average annual ımports beıng £10,000,000. with the exceptıon of the quantıty of silver won from the ǀwın ores and slags, no silver ıs produced ın the country. productıon from the above source, however, has shown rked ıncrease. The silver content of the Bawdwin lead- varıes from 10–30 ozs per ton of lead, and with the y ıncrease ın the output of lead of late years there has a corresponding rise ın the amount of sılver raısed. In the figures touched 4,500,000 ozs, valued at over a of rupees.

Silver.

;onsıderable amount of zınc ıs obtaıned in the mınıng of a from the Bawdwin mınes The ore ıs blende ıntımately l with galena. The average yearly output of zınc was , 90 tons, but ın the year 1923 the quantity raised nly ıncreased to 18,000 tons. It ıs thought that the wın zinc deposıts wıll prove as ımportant as, ıf not more ·tant than, the lead deposıts in the near future.

Zınc.

,h the exception of a few isolated occurrences of cassi- crystals in Palanpur and its occurrence *ın sıtu* ın the ic rocks of Hazaribagh, the only deposits of tin ore, ·rkable proportions, are those of Burma—the Mergui 'avoy districts of Lower Burma.[1] The most important ɘ is cassiterite, occurring in granitic intrusions traversing cıent schistose series of rocks (provisionally named the i series), and also in pegmatitic veins intersectıng both cks. But the greatest proportion of the ore ıs obtained, om the deposits *in sıtu*, but from the washing of river- s (*stream-tın* or *tin-stone*) and from dredging the river- ıf the tin-bearing areas, where the ore is collected by a s of natural concentration by running water. The of the total amount of tin produced in Burma has) risen to nearly Rs. 2,800,000 per year, of which the , share belongs to Tavoy.

Tin ore of Merguı and Tavoy.

G S I. vols xxxvıi. and xxxvııı. pts. 1, 1908 and 1909, Annual

Wolfram.

Wolfram of Tavoy.

Previous to 1914, Burma contributed nearly a third of the total production of wolfram of the world, but since then it has increased its output to a much larger extent The most important and valuable occurrences of wolfram are in the Tavoy district of Lower Burma,[1] where the tungsten-ore is found in the form of the mineral wolframite in a belt of granitic intrusions among a metamorphic series of rocks (*Mergui series*). The tin-ore, cassiterite, mentioned on the preceding page, occurs in the same group of rocks, though not associated with wolframite Wolfram occurs in quartz-veins or lodes, associated with minerals like tourmaline, columbite, and molybdenite. From its mode of occurrence as well as from its association with the above-named minerals, it is clear that wolfram is of pneumatolytic origin, *i e* formed by the action of "mineralising" gases and vapours issuing from the granitic magma The cassiterite has also originated in a similar manner

Wolfram is also found in India in Nagpur, Trichinopoly and Rajputana, but not in quantities sufficient to support a mining industry. The Burma deposits yielded 3680 tons of tungsten ore in 1916, valued at over 73 lacs of rupees. But the output of late has fallen off to some 900 tons yearly.

Uses of tungsten.

Tungsten possesses several valuable properties which give to it its great industrial and military utility. Among these the most important is the property of "self-hardening," which it imparts to steel when added to the latter. All high-speed steel cutting-tools have a certain proportion of tungsten in them. Tungsten-steel is largely used in the manufacture of munitions, of armour plates, of the heavy guns, etc , which enables them to stand the heavy charge of modern explosives Tungsten, by repeated heating, is given the property of great ductility, and hence wires of extreme fineness and great strength, suitable for electric lamps, are manufactured. The value of tungsten-ore (wolframite) was more than £80 per ton before the great rise in the industry during the war.

[1] *Rec G S.I.* vol xliii. pt 1, 1913.

Chromium.

Occurrence.

Chromite, the principal ore of chromium, occurs as a product of magmatic differentiation in the form of segregation masses and veins in ultra-basic, intrusive rocks, like dunites, peridotites, serpentines, etc In such form it occurs in Baluchistan, Mysore and in Singhbhum. The Baluchistan deposits are the most important and have the largest output, producing about 25,000 tons per year, valued at Rs 375 000 Chromite occurs in the Quetta and Zhob districts in the serpentines associated with ultra-basic intrusions of late Cretaceous age. The Mysore and Singhbhum deposits produced respectively 2600 and 1000 tons in 1923. Some chromite occurs in the "Chalk hills" (magnesite-veins) near Salem, but it is not worked.

Uses.

Chromite is used in the manufacture of refractory bricks or furnace-linings. Its further use lies in its being the raw material of chromium. An alloy of chromium and iron (ferro-chrome) is used in the making of rustless and stainless steels and armour-plates. A large part of chromium is used in the manufacture of mordants and pigments, because of the red, yellow and green colours of its salts.

Ores of the following metals also occur in India, but their deposits are of very limited proportions and are not of any considerable economic value.

Antimony.

Sulphide of antimony, stibnite, is found in deposits of considerable size at the end of the Shigri glacier in the province of Lahoul, but the lodes are inaccessible. It occurs mixed with galena and blende in the granitoid gneiss of that area. Stibnite is also found in Vizagapatam and in Hazaribagh. But the production of stibnite from these bodies is variable, and there does not appear to be any commercial possibility for them unless metallic antimony is extracted on the spot.

Arsenic.

Sulphides of arsenic, orpiment and realgar, form large deposits in Chitral on the North-West Frontier and in Kumaon. The orpiment-mines of the first locality are well known for the beautifully foliated masses of pure orpiment occurring in them, and form the chief indigenous source but the output has fallen off considerably of late years. The chief use of orpiment is as

a pigment in lacquer-work, it is also employed in pyrotechnics because of its burning with a dazzling bluish-white light [1]

Cobalt and nickel

Cobalt and Nickel-ores are not among the economic products of India. A few crystals of the sulphide of both these metals are found in the famous copper-mines of Khetri, Jaipur, Rajputana. The *Sehta* of the Indian jewellers is the sulphide of cobalt, which is used for the making of blue enamel Nickeliferous pyrrhotite and chalcopyrite occur at some places in South India, *e g* in the auriferous quartz-reefs of Kolar, in Travancore, etc, but the occurrences are not of sufficient magnitude to support mining operations.

Zinc Besides the ore associated with the lead-ores of Bawdwin (p 306), some zinc occurs with the antimony deposits of Shigri, and the copper-deposits of Sikkim Smithsonite is found at Udaipur in Rajputana and a few other places.

7. PRECIOUS AND SEMI-PRECIOUS STONES.[2]

Diamonds.

In ancient times India had acquired great fame as a source of diamonds, all the celebrated stones of antiquity being the produce of its mines, but the reputation has died out since the discovery of the diamond-mines of Brazil and the Transvaal, and at the present time the production has fallen to a few stones annually of but indifferent value Even so late as the times of the Emperor Akbar, diamond-mining was a flourishing industry, for the field of Panna alone is stated to have fetched to his Government an annual royalty of 12 lacs of rupees. The localities noted in history as the great diamond centres were Bundelkhand (for "Panna diamonds"); the districts of Kurnool, Cuddapah, Bellary, etc., in the Madras Presidency (for the "Golconda diamonds"); and some places in Central India such as Sambalpur, Chanda, etc. The diamondiferous strata in all cases belong to the Vindhyan system of deposits A certain proportion of diamonds were also obtained from the surface-diggings and alluvial-gravels of the rivers of these districts Two diamond-bearing horizons occur among the Upper Vindhyan rocks of Central India: one

Panna and Golconda diamonds

[1] Coggin Brown, *Bulletin of I I and L* No 6, 1921

[2] Goodchild, *Precious Stones* (Constable)

ıese (Panna State) ıs a thın conglomerate-band separatıng Kaımur sandstone from the Rewah serıes, and the other, a conglomerate, lıes between the latter and the Bhander s The dıamonds are found as rolled pebbles, lıke the r pebbles of these conglomerates, all derıved from the older s The orıgınal matrıx of the gem from which ıt separated by crystallısatıon, is not known with certaınty Probably ıs ın the dykes of basıc volcanıc rocks assocıated with the war series [1] The most famous dıamonds of Indıa from the ·e-noted localıties are: the "Koh-i-noor," 186 carats; "Great Mogul," 280 carats, the "Orloff," 193 carats; 'Pıtt" 410 carats; the value of the last-named stone, ıt to 136¾ carats, ıs estımated at £480,000

ies and Sapphires (Corundum).[2]

ystallısed and transparent varıetıes of corundum, when beautıful red colour, form the hıghly valued jewel ruby, when of a lıght blue tınt, the gem sapphıre Rubıes of carmine-red colour, "the colour of pıgeons' blood," and ct lustre are often of greater value than dıamonds es are mined at the Mogok dıstrıct (Ruby Mınes dıstrıct) ɔper Burma, north of Mandalay, whıch has been a cele- d localıty of thıs gem for a long tıme. The best rubies e world come from this dıstrıct from an area coverıng 25 to 30 sq. mıles, of whıch Mogok is the centre. The x of the ruby ıs a crystallıne lımestone—ruby lımestone ›. 54)—assocıated wıth and forming an ıntegral part of ırroundıng gneısses and schısts The rubıes are found *tu* in the lımestone along with a number of other dary minerals occurring ın ıt Some stones are also ıed from the hıll-wash and alluvıal detrıtus. The out- of the Burma ruby-mines amounted, some years to over £95,000 annually, but ıt has declined of late [3]

Burma rubies

› Burma ruby area also yields sapphires occasionally,

Sapphires of Kashmir.

[1] denburg, *Rec G S I* vol xxxııı. pt 3, 1906.

[2] ɔrundum," T H Holland, 1898, *G S I*

[3] › ruby from the Mogok mınes, 38½ carats ın weıght, was sold for ' ın London ın 1875

but a larger source of sapphires in India was up till lately Kashmir. The gem was first discovered in Kashmir in 1882; it there occurs as an original constituent of a fine-grained highly felspathic gneiss at Padar in the Kishtwar district of the Zanskar range, at a high elevation. Sapphires were also obtained from the talus-débris at the foot of the hill-slopes. Stones of perfect lustre and of high degree of purity have been obtained from this locality in the earlier years, but the larger and more perfect crystals, of value as gems, appear to have become exhausted since 1908, and the present output is confined to what are called "rock-sapphires," quite valueless for gems and of use only as abrasives, watch jewels, etc

Spinel.

Spinel when of sufficient transparency and good colour is used in jewellery; it constitutes the gem ballas-ruby when of rose-red colour and spinel-ruby when of a deeper red. Rubicelli is the name given to an orange-red variety. Spinel-rubies occur in the Burmese area associated with true rubies; also to some extent in Ceylon, in the well-known gem-sands of Ceylon, along with many other semi-precious and ornamental stones

Beryl.

Emeralds and aquamarines

Beryl when transparent and of perfect colour and lustre is a highly valued gem. Its colour varies much from colourless to shades of green, blue or even yellow. The much-prized green variety is the *emerald*, while the blue is distinguished as *aquamarine*. Emeralds are rare in India. Aquamarines suitable for use as gems are obtained from pegmatite-veins crossing the Archaean gneiss at some places in Behar and Nellore. Good aquamarines also occur in the Coimbatore district and in Kishengarh (Rajputana), from both of which localities stones of considerable value were once obtained. Recently a new and highly productive locality for aquamarines has been discovered in the Kashmir State in the Shigar valley in Skardu, from whence crystals of considerable size and purity are recovered

Common beryl occurs in very large crystals, sometimes a

ot in length, in the granite-pegmatite of many parts of idia, but only rarely do they include some transparent fragents of the required purity.

irysoberyl.

Chrysoberyl is a stone of different composition from beryl is of greenish-white to olive-green colour A few good ones in the form of platy crystals of tabular habit are obtained om pegmatite-veins in Kishengarh in Rajputana, which also eld mica and aquamarines. They are found in some felspar-ins in the nepheline-syenites of Coimbatore. Usually they e too much flawed and cracked to be suitable for cutting as ms. Chrysoberyl crystals when possessing a chatoyant lustre e known as "Cat's eyes" *Alexandrite* is the deep emerald-een variety found in Ceylon.

irnets.

Garnet as a gem-stone

Garnet possesses some of the requisites of a gem-stone—high refractive index and lustre, a great hardness, a pleasing lour, transparency, etc.—and would be appreciated as such, ire it but put on the market in restricted quantities Garnets e most abundant in the metamorphosed rocks of Rajputana d Ceylon, especially in the mica-schists, and large trans-rent crystals are frequently found Quantities of garnets e exported to foreign countries for use in cheap jewellery. ie variety used for this purpose is almandine, of crimson to l and violet colours. Crystals of large size are worked at ipur, Delhi and at Kishengarh, where they are cut into rious shapes for gems Those of Kishengarh are considered be the finest in India, and support a regular industry of out a lac of rupees yearly.

Zircons occur in various parts of India, but nowhere quite wless or with the degree of transparency required in a gem. *'acinth* (the transparent red variety) is found at Kedar Nath the Ganges.

urmalines.

Red and green tourmalines.

'ellucid and beautifully coloured varieties of tourmaline, , green or blue, are worked as gems The fine red

transparent variety *Rubellite* is obtained from the ruby-mines district of Burma, where it occurs in decomposed granite veins. The green variety known as *Indicolite* occurs in Hazaribagh (Bengal) and in the Padar district of Kashmir, where also some transparent crystals of rubellite are found. The latter tourmalines possess greater transparency, but are much fissured. Gem-tourmalines are also obtained from Ceylon from the noted gem-sands or gravels of that island.

Other gem-stones of India.

Besides the above-named varieties, other crystallised minerals, when of fine colour and attractive appearance and possessing some of the other qualities of gems, *e g* hardness, transparency, etc., are cut for ornamental purposes in different parts of the country. Among such minerals are the pleochroic mineral iolite or cordierite of Ceylon; kyanites or cyanites found at Narnaul in the Patiala State; rhodonite (pink manganese silicate) of some parts of the Central Provinces; apatite (a sea-green variety) met with in the kodurites of Vizagapatam. Moonstone and amazon-stone are ornamental varieties of felspar, the former a pearly opalescent orthoclase, met with in Ceylon, and the latter a green microcline occurring in Kashmir and elsewhere.

Gem-cutting is a regular industry in places like Delhi, Jaipur and Ceylon.

Agates.

Various forms of chalcedonic silica, agates, carnelian, blood-stone, onyx, jasper, etc., are known under the general name of *akik* (agate) in India. The principal material of these semi-precious stones is obtained from the amygdaloidal basalts of the Deccan, where various kinds of chalcedonic silica have filled up, by infiltration, the steam-holes or cavities of the lavas. The chief place which supplies raw *akik* is Ratanpur in the Rajpipla State, where rolled pebbles of these amygdales are contained in a tertiary conglomerate. On mining, the stones are first baked in earthen pots, which process intensifies the colouring of the bands in the agates. The cutting and polishing is done by the lapidaries of Cambay, who fashion out of them (after a most wasteful process of

pping), a number of beautiful but small articles and orna-
nts The annual output at Ratanpur is about 100 tons
nbay used to be a large market of Indian agates in past
.rs for different parts of the world.

łock-Crystal, or crystallised, transparent quartz, is also cut
ornamental objects, such as cheap jewels (*vallum* diamonds),
›s, handles, etc. The chief places are Tanjor, Kashmir,
labagh, etc., from whence crystalline quartz of requisite
'ity and transparency is obtained.

ıethyst and Rose-Quartz.

'he purple and pink-coloured varieties of rock-crystal are
as ornamental stones and gem-stones These occur in
ıe geodes, filling up lava-cavities, near Jabalpur

ımber is mineral resin, *i.e.* the fossilised gum of extinct
ıferous trees It is extracted by means of pits from some
cene clay-beds in Burma. A few cwts are produced
ually, from 50 to 200, with an average value of 90 to
rupees per cwt. It occurs in round fragments and lumps,
ısparent or translucent, often crowded with inclusions and
ı veins of calcite. Amber is employed in medicine, in
arts, for jewellery, etc., and is highly prized when of a
ısparent or translucent nature.

8. ECONOMIC MINERALS AND MINERAL PRODUCTS

ere we shall consider the remaining economic mineral
lucts, mostly non-metallic minerals of direct utility or
ıpplication in the various modern industries and arts.
y include salts and saline substances, raw materials for
ımber of manufactures, and substances of economic value
ı as abrasives, soil-fertilisers, the rare minerals, etc. With
rd to their geological occurrence, some are found as
tituents, original or secondary, of the igneous rocks ; some
›eds or lenticels among the stratified rocks, formed by

chemical agencies; while others occur as vein-stones or gangue-materials occurring in association with mineral-veins or lodes or as filling up pockets or cavities in the rocks. The more important of these products are :

1. Salt.	12 Gypsum.
2. Saltpetre.	13 Magnesite.
3. Alum	14 Asbestos.
4 Borax	15 Barytes
5 Reh.	16 Fluor-spar
6 Mica	17. Phosphatic Rocks
7 Corundum	18 Mineral Paints.
8. Jade	19 Uranium and Titanium Minerals.
9 Monazite	20 Rare Minerals
10 Graphite	21 Pyrite
11 Steatite	22. Sulphur.

Salt.

Salt.

There are three sources of production of this useful material in India: (1) sea-water, along the coasts of the Peninsula; (2) brine-springs, wells and salt-lakes of some arid tracts, as of Rajputana and the United Provinces; (3) rock-salt deposits contained in the Salt-Range and in the Kohat region. The average annual production of salt from these sources is a little over $1\frac{3}{4}$ million tons, the whole of which is consumed in the country The first is the most productive and an everlasting source, contributing more than 80 per cent of the salt consumed in India. The manufacture is carried on at some places along the coasts of Bombay and Madras, the process being mere solar evaporation of the sea-water enclosed in artificial pools or natural lagoons. A solid pan of salt results, which is afterwards refined by recrystallisation. Concentration from brine springs and wells is carried on in various parts of the United Provinces, Behar, Delhi, Agra, the delta of the Indus, Cutch and in Rajputana. The principal sources of salt in the last-named province are the salt-lakes of Sambhar in Jaipur, Dindwana and Phalodi in Jodhpur, and Lonkara-Sur in Bikaner The salinity of the lakes in this area of internal drainage was for long a matter of conjecture, but

Sources of Indian salt

Sea-water

Brine-wells.

e recent investigations of Holland and Christie [1] have con-
usively shown that the salt is brought as fine dust by the
uth-west monsoon from the Rann of Cutch and from the
a-coasts, and is dropped in the interior of Rajputana when
e velocity of the winds passing over it has decreased.

Rock-salt mines

The rock-salt deposits of Northern India also constitute an
mense and inexhaustible source of pure crystallised sodium
oride At Khewra, in the Jhelum district, two beds of
ck-salt 550 feet thick are worked ; they contain five seams of
re salt totalling 275 feet intercalated with only a few earthy
impure layers unfit for direct consumption. The horizontal
ension of these beds or lenticles is not known definitely, but
s thought to be great. Smaller salt-mines are situated at
ne other parts along these mountains A salt-deposit of
n greater vertical extent than that worked at Khewra is
l bare by the denudation of an anticline in the Kohat
trict, lying north of the Salt-Range. Here the salt is taken
by open quarrying in the salt-beds at the centre of the
icline near Bahdur Khel. The thickness of the beds is
0 feet and their lateral extent 8 miles The salt is nearly
e crystallised sodium chloride, with a distinct greyish tint
ng to slight bituminous admixture.

Other salts

'he Salt-Range deposits contain, beside sodium chloride,
ie salts of magnesium and potassium. The latter salts
of importance for their use in agriculture and some indus-
s. Dr. Christie has found numerous seams of potash-
ing minerals (containing a potassium percentage from
) 14 per cent.), such as *sylvite, kainite, langbeinite,* etc.,
erally underlying the layers of red earthy salt (*kalar*).[2]
arbonate and sulphate of soda were formerly derived from
reh efflorescences of the alluvial plains of Northern India.
bonate of soda forms a large ingredient of the salt-water
he Lonar lake, in Buldana district, which was formerly
acted for commerce. But the cheap supply of chemically
ufactured soda prohibits any industrial working of these
now.[3]

[1] *Rec. G S.I* vol. xxxviii. pt. 2, 1909.
[2] *Rec G S I.* vol. xliv pt. 4, 1914.
[3] *Rec. G S I* vol. xli pt 4, 1912.

Saltpetre or Nitre (Potassium Nitrate).[1]

India, principally the province of Behar, used to export this compound in very large amounts before the introduction of artifically manufactured nitrate, and constituted the most important source of supply to Europe and the United States of America

Mode of occurrence of nitre

Saltpetre is a natural product formed in the soil of the alluvial districts by natural processes under the peculiar conditions of climate prevailing in those districts. The thickly populated agricultural province of Behar, with its alternately warm and humid climate, offers the most favourable conditions for the accumulation of this salt in the sub-soil. The large quantities of animal and vegetable refuse gathered round the agricultural villages of Behar are decomposed into ammonia and other nitrogenous substances ; these are acted upon by certain kinds of bacteria (*nitrifying* bacteria) in the damp hot weather, with the result that at first nitrous and then nitric acid is produced in the soil This nitric acid readily acts upon the salts of potassium with which the soil of the villages is impregnated on account of the large quantities of wood and dung ashes constantly being heaped by villagers around their habitations The nitrate of potassium thus produced is dissolved by rain-water and accumulated in the sub-soil, from which the salt re-ascends to the surface by capillary action in the period of desiccation following the rainy weather. Large quantities of nitre are thus left as a saline efflorescence on the surface of the soil along with some other salts, such as chloride of sodium and carbonate of sodium

Its production

The efflorescence is collected from the soil, lixiviated and evaporated, and the nitre separated by fractional crystallisation. It is then sent to the refineries for further purification. In past years Behar alone used to produce more than 20,000 tons of nitre per year The present aggregate export of nitre from Behar, Punjab, Sind and other parts of India hardly amounts to 17,000 tons, valued at about Rs. 5,300,000.

Uses.

The chief use for nitre or saltpetre was in the manufacture of gunpowder and explosives before the discoveries of modern

[1] Hutchinson, "Saltpetre, its Origin and Extraction in India," *Bulletin* 68 (1917), Agricultural Department of India

ıemıstry brought ınto use other substıtutes for these purposes. ıtre ıs employed ın the manufacture of sulphuric acid and an oxidıser ın numerous chemical processes. A subordinate e of nıtre ıs as manure for the soıl.

um.

Alums are not natural but secondary products manufactured ; of pyritous shales or 'alum shales'

Pyritous shales when exposed to the aır, under heat and moise, gıve rise to the oxidatıon of the pyrıtes, producıng ıron ɔhate and free sulphurıc acıd The latter attacks the alumına ,he shales and converts ıt ınto alumınıum sulphate On the ıtıon of potash-salts, such as nitre or common wood-ashes, ısh-alum ıs produced, and when common salt or other soda- ; are introduced, soda-alum ıs produced. In thıs way several ns are made, dependıng upon the base added

Production

he natural weatherıng of the shales being a very slow process, expedited ın the artıficıal productıon of alum by roastıng ıt. roasted shale ıs then lixıviated and concentrated A mıxture arıous soda and potash-salts ıs then added and the alum ved to crystallıse out.]

he most common alums produced in Indıa are soda and sh alums. There was a flourıshing alum industry ın the ın Cutch, Rajputana and parts of the Punjab. But it is ɔnger remunerative in face of the cheap chemical manuired alums, and is carried on only at two localities, Kala-[1] and Cutch. The principal use of the alum manufactured dia is ın the dyeing and tanning industrıes.

luble sulphates of ıron and copper—copperas and blueɔl—are obtaıned as bye-products in the manufacture of ; from pyritous shales.

x.

ax occurs as a precıpıtate from the hot springs of the valley, Ladakh, whıch occur in assocıation wıth some ır deposits. Borax ıs an ingredient of many of the kes of Tıbet, along with the other salts of sodium. The of the Tıbetan lakes ıs obtained either by means of gs, on the shores of the lakes, or by the evaporation of vaters. The orıginal source of the borax ın these lakes

Borax from Tibet.

[1] *Rec. G.S.I.* vol. xl. pt. 4, 1910.

is thought to be the hot springs, like those of Puga mentioned on the preceding page.

Like nitre, alum and similar products, the borax trade, which was formerly a large and remunerative one, has seriously declined owing to the discovery of deposits of calcium borate in America, from which the compound is now synthetically prepared. The industry consisted of the importation of partly refined borax into the Punjab and United Provinces, from Ladakh and Tibet, and its exportation to foreign countries. About 16,000 cwts. were thus exported yearly, valued at Rs. 360,000, whereas now it is only about 4500 cwts. Borax is of use in the manufacture of superior grades of glass, artificial gems, soaps, varnishes and in soldering and enamelling.

Reh or **Kallar** is a vernacular name of a saline efflorescence composed of a mixture of sodium carbonate, sulphate and chloride, together with varying proportions of calcium and magnesium salts found on the surface of alluvial soils in the drier districts of the Gangetic plains. Reh is not an economic product, but it is described here because of its negative virtues as such. Some soils are so much impregnated with these salts that they are rendered quite unfit for cultivation. Large tracts of the country, particularly the northern parts of United Provinces, Punjab and Rajputana, once fertile and populous, are through its agency thrown out of cultivation and made quite desolate. The cause of this impregnation of the salts in the soil and sub-soil is this: The rivers draining the mountains carry with them a certain proportion of chemically dissolved matter, besides that held in mechanical suspension, in their waters. The salts so carried are chiefly the carbonates of calcium and magnesium and their sulphates, together with some quantity of sodium chloride, etc. In the plain-track of the rivers, these salts find their way, by percolation, into the sub-soil, saturating it up to a certain level. In many parts of the hot alluvial plains, which have got no underground drainage of water, the salts go on accumulating and in course of time become concentrated, forming new combinations by interaction between previously existing salts.

The origin of *reh* salts.

ın water, percolating downwards, dissolves the more ıble of these salts and brings them back to the surface ing the summer months by capıllary action, where they n a white efflorescent crust. The reclaımıng of these barren ar lands ınto cultıvable soils by the removal of these з would add millıons of acres to the agrıcultural area of a and brıng back under cultivatıon what are now altogether ıle uninhabited dıstrıcts

he carbonate and sulphate of soda, the chief constituents eh, were formerly of some use as a source of salts of lies, and were produced in some quantıty for local stry, but their productıon ıs no longer remunerative.

ı.

Uses of mica. ca (muscovite) finds ıncreased uses in many industries, ıs a valuable article of trade. The chief use is as an atıng materıal ın electrıc goods; another ıs as a sub-te for glass ın glazing and many other purposes For atter purpose, however, only large transparent sheets are suitable. Formerly an enormous amount of what led *scrap-mıca* (small pieces of flakes of mica), the waste ca-mınes and quarrıes, was consıdered valueless and was n away. A use has now been found for this substance making of *micanıte*—mica-boards—by cementing small f scrap mıca under pressure. Micanite is now employed any purposes in which sheet mica was formerly used. mica ıs also ground for making paınts, lubrıcants, etc.

mıca-deposıts of the Indıan peninsula are considered the finest ın the world, because of the large size and tıon of the crystal plates obtainable at several places. quality of the mica is due to the immunity from all ɔances such as crumpling, shearing, etc., of the parent Crystals more than three yards in diameter are ed occasionally from the Nellore mines, from which le flawless sheets of great thinness and transparency ven off

Mica-deposits of Nellore and Hazaribagh. ı is the largest producer of mica in the world, contri-of late years, more than 50,000 cwts. per year, bringing turn of Rs. 6,500,000. Although muscovite is a most

widely distributed mineral in the crystalline rocks of India, marketable mica is restricted to a few pegmatite-veins only, carrying large perfect crystals, free from wrinkling or foreign inclusions. These pegmatite veins cross the crystalline rocks, granites, gneisses and schists, but they become the carriers of good mica only when they cut through mica-schists. The principal mica-mining centres in India are the Hazaribagh, Gaya and Monghyr districts of Bengal, the Nellore district of Madras and Ajmere and Merwara in Rajputana. Of these Bengal is the largest producer, while Rajputana contributes only 4 per cent. of the total.[1] The dark-coloured micas, biotite, phlogopite, etc., have no commercial use.

Corundum.[2]

Occurrence.

Corundum is an original constituent of a number of igneous rocks of acid or basic composition whether plutonic or volcanic. It generally occurs in masses, crystals, or irregular grains in pegmatites, granites, diorites, basalts, peridotites, etc. The presence of corundum under such conditions is regarded as due to an excess of the base Al_2O_3 in the original magma, over and above its proper proportion to form the usual varieties of aluminous silicates.[3] India possesses large resources in this useful mineral, which are, for the most part, concentrated in Mysore and Madras. Corundum is distributed in the crystalline rocks of various other parts of India and Burma as well. The most important of these localities are: the Mogok district (Ruby Mines district), in Upper Burma, Assam (Khasia hills), and some parts of Bengal, the Zanskar range in Kashmir, etc. In Burma the famous ruby-limestone contains a notable quantity of corundum as an essential constituent of the rock, some of which has crystallised into the transparent varieties of the mineral, ruby and sapphire. In Madras there is a large area of corundum-bearing rocks covering some parts of Trichinopoly, Nellore, Salem and Coimbatore. Mostly the corundum

Distribution.

[1] "Mica Deposits of India," *Mem. G S I.* vol. xxxiv. pt. 2, 1902.

[2] "Corundum," T. H Holland, 1898, *G S.I.*

[3] In the above instances corundum occurs as an original constituent of the magma, but the mineral also occurs in many cases as a secondary product in the zones of contact-metamorphism around plutonic intrusions.

rs *in situ* in the coarse-grained gneisses, in small round ıs or in large crystals, measurıng some inches in size. It forms a constituent of the eleaolıte-syenites of Sıvamalai of the coarse felspar-rock of Coımbatore.

Uses

ıe chief use of corundum is as an abrasive material because great hardness. Emery ıs an impure variety of corundum, d with iron-ores and adulterated with spinel, garnet, The abradıng power of emery is much less than that of ıdum, whıle that of corundum agaın is far below that e crystallised varıety sapphire. As an abrasive corundum ow many rivals, in such artıficial products as *carborundum*, *lum*, etc. Corundum ıs used ın the form of hones, wheels, ler, etc., by the lapıdarıes for cutting and polishing gems, etc.

e total annual productıon in Indıa averages about 6000 00 cwts., valued at about Rs. 30,000.

Other abrasives

ııle dealıng wıth abrasıves, we might also consider here rials suitable for millstones and grindstones that are l in Indıa. A number of varieties of stones are quarried ıtting ınto millstones, though rocks that are the most ɔle for thıs purpose are hard, coarse grits or quartzites ı is a scarcity of such rocks in most parts of the country ence the stones commonly resorted to are granites, hard Vindhyan sandstones and Gondwana grıts and sand-ı, chiefly of the Barakar stage.

Millstones.

Grındstones.

ndstones, or honestones, are cut from any homogeneous grained rocks belonging to one or the other of the follow-ırietıes : fiue sandstones, lydite, novaculıte, hornstone, rained lava, slate, etc.

te.

e is a highly-valued ornamental stone on account of eat toughness, colour and the hıgh lustrous polish it It is especially valued in China, to which country ı the whole Indian output is exported. A large number ıeral compounds pass under the name of *jade*, but the ıineral, also named *nephrite*, so much sought after, is a ratively rare substance. Its occurrence is not known ıa, but a mineral very much similar to it in many of its

qualities and known as *jadeite*, is largely quarried in Burma True jade comes in India from the Karakash valley of South Turkestan.

Occurrence. The stones are of various shades of green, blue-green, blue, or milk-white colour. Jade belongs to the group of amphiboles, being allied mineralogically to the species Tremolite, while jadeite, resembling the latter in many of its physical characters, is more allied to the pyroxene group, being a species of Spodumene. The occurrence of the latter mineral in India is principally confined to the Miocene rocks of Upper Burma (Myitkyina district), where its extraction and export is a long-established and remunerative industry. It occurs either as boulders in the alluvial gravels or as an alteration-product in the large serpentinous intrusions in the district of Tawmaw[1] The formation of jade in serpentine is regarded by some as due to magmatic segregation taking place in the basic igneous intrusions of Miocene age. By others its presence is attributed to the effects of contact metamorphism on a dyke of nepheline-albite rock traversing masses of serpentine.

Its formation.

In the period of its greatest prosperity, the jade industry was a flourishing trade in Burma, but at present it has considerably lessened, which is to some extent due to the inferior quality of the jadestone obtained. In 1923 Burma exported 7800 cwts of jadestone of the aggregate value of Rs. 2,400,000.

Sang-e-Yeshm, regarded as jade in the Punjab, is only a variety of serpentine. It differs from the original mineral in all its characters, being not so tough, much softer and incapable of receiving the exquisite polish of jade.

Monazite is a phosphate of the rare earths—cerium, lanthanum and didymium—but its economic value depends upon a small percentage of thorium oxide, which it contains as an impurity Monazite was discovered some years ago in the Travancore State in river-detritus and along a long stretch of the coast from Cape Comorin to Quilon At some places the monazite-sands have been concentrated by the action of the

[1] Bleeck, *Rec. G S I.* vol xxxvi. pt 4, 1908.

sea-waves into rich pockets Besides monazite, the other constituents of the sand are magnetite, ilmenite. garnets, etc.; those with a high proportion of monazite have a density of 5 5 with a light yellow colour The monazite of Travancore is derived from the pegmatite-veins crossing the charnockites of the district Its original formation is ascribed to pneumatolytic agencies during the later period of consolidation of the charnockite magma It is also a small accessory constituent of the main rock. The percentage of thoria, yielded by the Travancore monazite, on which the commercial value of the mineral depends, is variable from 8 to 10 per cent. In 1918 India exported concentrated monazite sands of the value of £58,000 (2100 tons).[1]

Monazite of Travancore.

Its occurrence.

The industrial use of monazite lies in the incandescent properties of thoria and the other oxides of the rare earths which it contains. These substances are used in the manufacture of mantles and filaments for incandescent lamps.

Uses.

Graphite.

Graphite occurs in small quantities in the crystalline and metamorphic rocks of various parts of the Peninsula, in pegmatite and other veins, and as lenticular masses in some schists and gneisses. It forms an essential constituent of the rock known as Khondalite of Orissa. But the majority of these deposits are not of workable dimensions. Graphite occurring under such conditions is undoubtedly of igneous origin, *i.e.* a primitive constituent of the magma. Graphite resulting from the metamorphism of carbonaceous strata, and representing the last stage of the mineralisation of vegetable matter, is practically unknown in India, except locally in the highly crushed Gondwana beds of the Outer Himalayas. The largest deposits of graphite are in Ceylon, which has in the past supplied large quantities of this mineral to the world, its yearly contribution being nearly a third of the world's total annual produce. The graphite here occurs as filling veins in the granulites and allied gneisses. The structure of the veins is often columnar, the columns lying transversely to the veins. Travancore until lately was another important

Occurrence.

[1] Tipper, *Rec G S I.* vol. xliv. pt. 3, 1914

centre for graphite-mining, supplying annually about 13,000 tons of the mineral (valued at Rs. 780,000). The graphite industry has practically ceased in Travancore of late years owing to the increasing depths to which mining operations have become necessary.

A few other localities have been discovered among the ancient crystalline rocks, where graphite occurs, viz. Merwara in Rajputana, Sikkim, Coorg, Vizagapatam and in the Ruby Mines district of Upper Burma. But the quantity available is not large.

Uses.

The uses of graphite lie in its refractoriness and in its high heat conductivity. For this purpose it is largely employed in the manufacture of crucibles Its other uses are for pencil manufacture, as a lubricant, in electrotyping, etc.

Steatite.

Massive, more or less impure, talc is put to a number of minor uses. From its smooth, uniform texture and soapy feel, it is called soapstone. It is also known as pot-stone from its being carved into plates, bowls, pots, etc. Steatite is of wide occurrence in India, forming large masses in the Archaean and Dharwar rocks of the Peninsula and Burma, workable deposits occur in Behar, Jabalpur, Salem, Idar and Jaipur (Rajputana) and Minbu (in Burma). At most of these places steatite is quarried in small quantities for commercial purposes In its geological relations, steatite is often associated with dolomite (as in Jabalpur) and other magnesian rocks, and it is probable that it is derived from these rocks by metamorphic processes resulting in the conversion of the magnesium carbonate into the hydrated silicate. In other cases it is the final product of the alteration of ultra-basic and basic eruptive rocks. At Jabalpur and other places it is carved into bowls, plates and vases; it is also used in making pencils for writing on wood or cloth and as a refractory substance in making jets for gas-burners. The substance has also of late come into use as a paint of high quality for protecting steel

Mode of origin of steatite

Gypsum forms large bedded masses or aggregate occurring in association with rocks of a number of different geological

formations. It has not found many uses in India, as is shown by the extremely low price of the product, Re 1 for about 15 tons in some of the localities where it is quarried. Large deposits of gypsum occur in the Salt-Range and Kohat in association with rock-salt deposits, and in the Tertiary clays and shales of Sind and Cutch. In Jodhpur and Bikaner beds of gypsum are found among the silts of old lacustrine deposits and are of considerable economic interest locally. In Spiti the gypsum occurs in immense masses replacing Carboniferous limestones. In some cases gypsum occurs as transparent crystals (*selenite*) associated with clays The handsome massive and granular variety, known as *alabaster*, is used in Europe for statuary, while the silky fibrous variety, known as *satin-spar*, is employed in making small ornamental articles.

The industrial use of gypsum is in burning it for making plaster-of-Paris. It is also used as a surface-dressing for lands in agriculture

Magnesite.[1]

Large deposits of magnesite occur in the district of Salem as veins associated with other magnesian rocks such as dolomite, serpentines, etc The magnesite is believed to be an alteration-product of the dunites (peridotite) and other basic magnesian rocks of Salem. When freshly broken it is of a dazzling white colour and hence the magnesite-veins traversing the country have been named the Chalk hills of Salem. The magnesite of Salem is of a high degree of purity, is easily obtained and, when calcined at a high temperature, yields a material of great refractoriness. Other places in South India also contain magnesite-veins traversing basic rocks, viz. Coimbatore, Mysore and Trichinopoly. The industrial uses of magnesite are in the manufacture of refractory materials and as a source of carbonic acid gas. It is also manufactured into cement for artificial stone, tiles, etc.

Mode of occurrence of magnesite.

Asbestos.[2]

Two quite different minerals are included under this name: one a variety of amphibole resembling tremolite and the other

[1] Middlemiss, *Rec. G.S I.* vol. xxix. pt. 2, 1896

[2] Coggin Brown, *Bulletin of I. I. and L.* No. 20, 1922.

a fibrous variety of serpentine (chrysotile) Both possess much the same physical properties that make them valuable as commercial products. Asbestos (both the real mineral and chrysotile) has been discovered at many places in India, but at only one or two localities to be of any commercial use, viz the Mysore State and the Saraikala State in Singhbhum. Much of this asbestos, however, does not possess that softness or flexibility of fibre on which its industrial application depends Asbestos has found a most wonderful variety of uses in the industrial world of to-day, viz in the manufacture of fire-proof cloth, rope, paper, mill-boards, sheeting, belt, paint, etc., and in the making of fire-proof safes, insulators, lubricants, felts, etc

Asbestos (amphibole) occurs in pockets or small masses or veins in the gneissic and schistose rocks. The chrysotile variety forms veins in serpentine.

Barytes

Barytes occurs at many places in India in the form of veins and as beds in shales, in sufficient quantities, but with few exceptions the deposits are not worked because of the absence of any demand for the mineral The chief localities for barytes are Salem and Sleemanabad (in the Jabalpur district). Barytes is used as a pigment for mixing with white lead, as a flux in the smelting of iron and manganese, in paper-manufacture, in pottery-glazes, etc. The annual production approximates 2400 tons, valued at Rs. 5000.

Fluor-spar.

This mineral is of rather rare occurrence in India. Veins of fluorite occur in the igneous rocks of some parts of the Peninsula and the Himalayas as well as in a few limestones, but the quantity available is not considerable in any place. The chief use of fluor-spar is as a flux in the manufacture of iron, of opalescent glass, enamel, etc.

Phosphatic Deposits.

Native phosphates, as apatite, or rock-phosphates, as concretions, are highly valued now as artificial fertilisers or manures, either in the raw condition or after treatment with sulphuric acid, to convert them into acid or superphosphates.

Their rarity in a country like India, whose primary industry is agriculture, is most regrettable. The only known occurrence of phosphatic deposits on a sufficient scale is in connection with the Cretaceous beds of Trichinopoly, where phosphate of lime occurs in the form of septarian nodules disseminated in the clay-beds. The quantity available is about 8,000,000 tons. A like deposit near Mussoorie, overlying the Deoban limestone, is very rich in tri-calcium phosphate. Massive apatite occurs in the mica-pegmatites of Hazaribagh and in parts of Bombay and Madras.

Mineral Paints.

A number of rock and mineral substances are employed in the manufacture of paints and colouring materials in Europe and America. Substances which are suitable for this purpose include earthy forms of haematite and limonite (ochres, *geru*), refuse of slate and shale quarries, possessing the proper colour and degree of fineness; graphite; laterite; orpiment; barytes, asbestos, steatite, etc. Many of the above substances are easily available in various parts of India and some are actually utilised for paints and pigments, viz. a black slate for making black paints, laterite and *geru* (red or yellow levigated ochre) for red, yellow or brown colouring matters, barytes as a substitute for white lead; orpiment for yellow and red colours in lacquer work.[1]

Substances used for mineral paints.

Uranium and Titanium.

Pitchblende occurs in nodular aggregates, in patches of basic segregations in a pegmatite vein crossing the gneisses and schists in the Singar mica-mines at Gaya. It is associated with other uranium minerals—uranium-ochre, torbernite, and also columbite, zircon, triplite, etc These minerals have great commercial value because of the small proportion of radium that they contain. Recent investigations in the Gaya pitchblende deposits have proved that the latter are very promising in their radium-content Besides pitchblende, other radium-bearing minerals and radio-active earths have been found. Samarskite, a very rare mineral, is found in the mica-bearing pegmatite of Nellore and some parts of Mysore.

Pitchblende of Gaya.

[1] Coggin Brown, *Bulletin of I I. and L* No. 20, 1922.

Titanium occurs in its two compounds, ilmenite and rutile, the former of which is of fairly wide distribution in the charnockites and other gneisses of the Peninsula and Rajputana. It also occurs plentifully in some sands, *e.g* the monazite sands of Travancore

Rutile is also abundantly distributed throughout the crystalline schists of the Peninsula.

The Rare Minerals.

The rare minerals of India.

The pegmatite veins of the crystalline rocks of India contain a few of what are called the rare minerals as their accessory constituents The rare elements contained in them have found an extended use in modern industries such as mantle-manufacture, the manufacture of special kinds of steels, and other products of highly specialised uses in the present-day industries [1]

The most common of these are: wolfram and monazite, which have been already dealt with; columbite and tantalite (niobates and tantalates of the rare-earths), which occur in the mica-pegmatites of Gaya, Hazaribagh, Nellore, etc.; gadolinite (a silicate of the yttrium earths), which is found in a tourmaline-pegmatite associated with cassiterite in Palanpur; and molybdenite, which is found in the elaeolite-syenite-pegmatite of Rajputana and of Travancore. Another rare mineral, thorianite, has been found in Ceylon, containing from 60-80 per cent. of thoria and a considerable amount of helium.

Zircon is found with uranium minerals and with triplite in the mica-mines of Gaya and in the nepheline-syenites of Coimbatore Cyrtolite is a radio-active variety found in some of these localities.

Platinum and iridium occur as rare constituents of the auriferous gravels of some parts of Burma.

Pyrite.

Pyrite is a mineral of very wide distribution in many formations, from the oldest crystalline rocks to the youngest sediments, but nowhere is it locally abundant to be of com-

[1] Cahen and Wootton: *Mineralogy of the Rarer Metals*, 1912 (C. Griffin).

mercial utility in the preparation of sulphur and sulphuric acid. The economic value of pyrite[1] lies in its being a source of sulphur and not as an ore of iron, because the high proportion of sulphur in it is injurious to the iron. The only occurrences, of any considerable scale, are those of the pyritous shales of Kalabagh and the Dandot collieries on the Salt-Range, but the chances of sulphur manufactured out of these deposits to compete against imported sulphur are very few, and no attempt is made for its development Large stores of sulphur exist in connection with metallic sulphides, notably of copper and lead, which, when they are properly worked in India, will yield the metal as well as the sulphur.

Occurrence.

Sulphur in small quantities is obtained as a sublimation product from the crater of Barren Island volcano, from Sanni in the Kelat state, and from some of the extinct volcanoes of Western Baluchistan. Many of the sulphur springs precipitate some quantities of fine powdery sulphur near their outlets. Sulphur occurs in the Puga valley of Ladakh. It is found there both as a deposit from its hot springs and also as filling up fissures in quartz-schists.

These sources are, however, too insignificant to meet the demand for sulphur in the country which is satisfied wholly by imports from foreign countries Large reserves of sulphur are available in the lead-zinc-silver ores of Bawdwin (page 306), but their economic utilisation does not as yet seem probable.

Sulphur has many important uses, much the most important being the manufacture of sulphuric acid. With regard to the last-named compound we may quote the following valuable statement: "Sulphuric acid is a key to most chemical and many metallurgical industries; it is essential for the manufacture of superphosphates, the purification of mineral oils, and the production of ammonium sulphate, various acids, and a host of minor products; it is a necessary link in the chain of operations involved in the manufacture of alkalies, with which are bound up the industries of making soap, glass, paper, oils, dyes, and colouring matter; and, as a bye-product, it permits the remunerative smelting of ores which it would

Sulphuric acid.

[1] Fox, *Bulletin of I I. and L.* No. 28, 1922.

be impossible otherwise to develop During the last hundred years the cost of a ton of sulphuric acid in England has been reduced from over £30 to under £2, and it is in consequence of the attendant revolution in Europe of chemical industries, aided by increased facilities for transport, that in India the manufactures of alum, copperas, blue vitriol and alkalies have been all but exterminated ; that the export trade in nitre has been reduced instead of developed , that the copper and several other metals are no longer smelted , that the country is robbed every year of over 90,000 tons of phosphate fertilisers, and that it is compelled to pay over 20 millions sterling for products obtained in Europe from minerals identical with those lying idle in India." [1]

We shall close this chapter on economic geology with a few remarks on the soils of India.

SOILS

Soil formation

The soils of all countries are, humanly speaking, the most valuable part of the regolith or surface rocks. They are either the residue of the underlying rocks, after the other soluble constituents are removed, mingled with some proportion of decomposed organic matter (*residual soil*) , or the soil-cap may be due to the deposition of alluvial débris brought down by the rivers from the higher grounds (*drift soil*). The soil of the Peninsula, for the greater part, is of the first description, while the great alluvial mantle of North India, constituting the largest part of the most fertile soil of India, is of the second class We can easily imagine that in the production of soils of the first kind, besides the usual meteoric agencies, the peculiar monsoonic conditions of India, giving rise to alternating humidity and desiccation, must have had a large share. These *residual* soils of the Peninsula show a great variety both in their texture and in their mineralogical composition, according to the nature of the subjacent rock whose waste has given origin to it. They also exhibit a great deal of variation in depth, consistency, colour, etc. However, the soils of India, so far as their geological peculiarities are

[1] *Rec. G S I.* vol xlvi, 1915, p. 295.

cerned, show far less variation than those in other ntries, because of the want of variety in the geological nations of India.

The soils of India.

'ver the large areas of metamorphic rocks the disintegra- of the gneisses and schists has yielded a shallow sandy tony soil, whereas that due to the decomposition of the ılts of the Deccan, in the low-lying parts of the country, highly argillaceous, dark, loamy soil. This soil contains, des the ordinary ingredients of arable soils, small quantities ıe carbonates of calcium and magnesium, potash, together ı traces of phosphates, ingredients which constitute the f material of plant-food that is absorbed by their roots. latter soil is, therefore, much more fertile as a rule than former The soil of the metamorphic rocks is thin and low in general (except where it has accumulated in the ›y-basins), because of the slowness with which the ıses and schists weather. The soil in the valleys is good, use the rain brings the decomposed rock-particles and ers them in the hollows In these situations of the cry- ıne tract the soils are rich clay-loams of great productive-

Soils of sedimentary rocks.

ıe soils yielded by the weathering of the sedimentary ı depend upon the composition of the latter, whether be argillaceous, arenaceous or calcareous. Soils capping Gondwana outcrops are in general poor and infertile, ıse Gondwana rocks are coarse sandstones and grits but little of cementing material. Argillaceous and re calcareous rocks yield good arable soils. Reference here be made to the remarkable black soil, or "regur," of areas of the Deccan which has already been described ıge 268. The greater part of Rajputana, Baluchistan he Frontier Provinces are devoid of soils, because the ıions requisite for the growth of soil by any of the two ıses are altogether absent there. The place of soil is by another form of regolith The loess caps of the · parts of the Punjab possess many of the qualities of cellent soil, but its high porosity tends to lower the ground water-table to inaccessible depth.

Alluvial soils.

alluvial soils of the great plains of the Indus and

Ganges, as also of those of the broad basins of the Peninsular rivers, are of the greatest value agriculturally. They show minor variations in density, colour, texture and porosity besides difference in composition, from district to district, but in general are light-coloured loamy soils of a high degree of productiveness, except where it is destroyed by the injurious *reh* salts. There are, however, a number of circumstances which determine the characters and peculiarities of soils and their fertility or otherwise; this subject is, however, beyond the scope of this book and cannot be discussed further.

CHAPTER XXVII. (APPENDIX)

GEOLOGY OF KASHMIR

The object of the present chapter is to give in brief outline the geology of a province which contains, within a small geographical compass, one of the finest developments of the stratified record seen in the Indian region and perhaps in the world. A very large section of the fossiliferous geological record is exhibited in the hills and mountains surrounding the beautiful valley of Kashmir in localities easily accessible to students, and thus offering facilities for the study of the stratigraphical branch of the science, which are met with in no other parts of India. In this happy combination of circumstances the Vale of Kashmir is unique as an excursion ground for students of geology, as much for its wealth of stratigraphic results, as for its physiographic phenomena, its orographic features, its glaciers, etc. For this reason a connected account of the geology of Kashmir is appended as a special chapter.

We shall describe in the present chapter the geology and physical features of the country comprised within the territories of the Jammu and Kashmir State, lying between the Ravi and the Chenab valleys constituting a large area in the North-West Himalayas. Incidentally, therefore, the subject of this chapter will also be a recapitulation of the main facts of the orography and geology of one of the best explored parts of the Himalayas.

PHYSICAL FEATURES

The chief orographic features.

An admirable account of the geography of this region is given by Frederic Drew in his well-known book, *Jammu and*

Kashmir Territories (E Stanford, London, 1875). What follows in this section is an abridgement from this author's description, modified, to some extent, by incorporating the investigations of later observers. The central Himalayan axis, after its bifurcation near Kulu, runs as one branch to north-west, known as the Zanskar Range, terminating in the high twin-peaks of Nun Kun (23,447), the other branch runs due west, a little to the south of it, as the Dhauladhar Range ("the Great Himalayan Range" of Col. Burrard), extending further to the north-west as the high picturesque range of the Pir Panjal, so conspicuous from all parts of the Punjab Between these two branches of the crystalline axis of the Himalayas lies a longitudinal valley with a south-east to north-west trend, some 84 miles long and 25 miles broad in its middle, the broadest part. The long diameter of the oval is parallel to the general strike of the ranges in this part of the Himalayas. The total area of the Kashmir valley is 1900 sq. miles, its mean level about 5200 feet above the sea The ranges of mountains which surround it at every part, except the narrow gorge of the Jhelum at Baramula, attain, to the north-east and north-west, a high general altitude, some peaks of which rise above 18,000 feet. On the south-western border, the bordering ridge, the Pir Panjal, is of comparatively lower altitude, its mean elevation being 14,000 feet The best known passes of the Pir Panjal range, the great high-ways of the past, are the Panjal Pass, 11,400 feet, Golabghar Pass, 12,500 feet; the Banihal Pass, 9700 feet, Tata Kuti and Brahma Sakal are the highest peaks, above 15,500 feet in elevation.

The Outer Ranges (the Sub-Himalayas or the Siwalik Ranges).

The outer ranges.

The outermost ranges of the Kashmir Himalayas rise from the plains of the Punjab, commencing with a gentle slope from Jammu, attain to about 2000 feet altitude, and then end abruptly in a steep almost perpendicular escarpment inwards.

Their simple geological structure.

Then follows a succession of narrow parallel ridges with their strike persistent in N.W.-S.E. direction, separated by more or less broad longitudinal or strike-valleys (the basins of

sequent streams) These wide longitudinal or strike- 'eys inside the hills are of more frequent occurrence in the ,ern parts of the Himalayas, and attain a greater pro- ence there, being known there as "duns" (e g Dehra Dun, hri Dun, Patli Dun, etc). The Kashmir valley itself may be ,n as an exaggerated instance of a dun in the Middle ıalayas. These outer hills, formed entirely of the younger ıiary rocks, rarely attain to greater altitude than 4000 feet ıereabouts. The outer ranges of the Sub-Himalayan zone, ıded by the Ravi and the Jhelum, the two east and west ıdaries of the Kashmir State, are known as the Jammu Structurally, as well as lithologically, they partake of ıame characters as are seen in the hills to the east and of it, which have received a greater share of attention he Indian geologists Ranges situated more inwards, formed of older Tertiary rocks (of the Murree series), a higher altitude, about 6000 to 8000 feet. At the exit e great rivers, the Chenab and the Jhelum, there is an tation or a deep flexure inwards into this region corre- ing to an abrupt change in the direction of the strike of ıılls. In the case of the Jhelum at Muzafferabad this ə is far more conspicuous and significant, the strike of hole Himalayan range there changing from the usual east—north-west to north and south and thence ;oing another deflection to north-east—south-west.

The "duns."

Iiddle Ranges (Lesser or Middle Himalayas—The 'anjal and Dhauladhar Range).[1]

region consists of higher mountains (12,000–15,000 feet) o by deep ravines and precipitous defiles. The form e ranges bears a great contrast to the outer hills de- above, in being ridges of irregular direction that branch ınd again, and exhibiting much less correspondence ı the lineation of the hills and the strike of the beds ıting them. In the Pir Panjal, which may be taken as ıf the mountains of the Middle Himalayas, these ridges

The Panjal range.

connected account of the geology of Pir Panjal, see Middlemiss, xli. pt. 2, 1911, and Wadia, "Geology of Poonch and Adjoining em. G.S.I. (in the press).

"Ortho-clinal" structure of the Middle ranges.

present generally a steep escarpment towards the plains and a long gentle slope towards Kashmir. Such mountains are spoken of as having an "orthoclinal" structure, with a "writing-desk" shape (see fig. 31, p. 343) To this cause (among several others) is due the presence of dense forest vegetation, the glory of the Middle Himalayas, clothing the north and north-eastern slopes, succeeded higher up by a capping of snows, while the opposite, southern slopes are, except in protected valley-slopes, barren and devoid of snow, being too steep to maintain a soil-cap for the growth of forests or allow the winter-snows to accumulate. Geologically the Middle Himalayas of this part are different from the foot-hills, being composed of a zone of highly compressed and altered rocks of various ages, from Silurian to Eocene. The axial zone of the Panjal range is composed of the Permo-Carboniferous. For map of the Pir Panjal, see Pl. XV.

Inner Himalayas.

The zone of highest elevation.

To the north of the Pir Panjal range, and enclosing between them the valley of Kashmir, are the more lofty mountain-ranges of the innermost zone of the Himalayas, rising above the snow-line into peaks of perpetual snow. In the Zanskar range, which forms the north-eastern border of the valley, there are peaks of from 15,000 to 20,000 feet in height. Beyond this range the country, with the exception of the deep gorges of the Middle Indus, is a high-level plateau-desert, utterly devoid of all kind of vegetation. Here there are elevated plateaus and high mountain-ranges separated from one another by great depressions, with majestic peaks towering to 24,000 feet. The altitude steadily increases farther north, till the peak K_2, on the mighty Karakoram or Mustagh range, attains the culminating height of 28,265 feet—the second highest mountain in the world. The Karakoram chain is the watershed between India and Turkestan. The valleys of these regions show varying characters. In the south-east is the Changchenmo whose width is from five to six miles, with a mean height of 14,000 feet above the sea-level. From that to the north-west the height of the valley-beds descends, till in Gilgit and its neighbourhood the

Physical aspects of the Inner Himalayas.

ivers have cut so deeply through the bare, bleak mountains hat the streams flow at an elevation of only 5000 and, in one ase, 3000 feet above the level of the sea. At places, in orth and north-east Kashmir, there are extensive flat, wide, lains or depressed tracts among the mountains, too wide to e called valleys, of which the most conspicuous are the lateaus of Deosai, 13,000 feet high, Lingzhitang, 16,000 feet, id Dipsang of about the same height. The physical features this extremely rugged, wind-swept and frost-bitten region ary much in character. They present an aspect of desolate, e-bound altitudes and long dreary wastes of valleys and pressed lands totally different from the soft harmony of the ashmir mountains, green with the abundance of forest id cultivation. The rainfall steadily diminishes from the irly abundant precipitation in the outer and middle ranges an almost total absence of any rainfall in the districts of idakh and Gilgit, which in their bleakness and barrenness rtake of the character of Tibet Owing to the great aridity the atmosphere, the climate is one of fierce extremes, from e burning heat of some of the desert tracts of the Punjab ins in the day, to several degrees below freezing-point at ght Baltistan, lying directly to the north of Kashmir, and eiving some share of the atmospheric moisture, has a climate ermediate between the latter and that of Ladakh. In isequence of the great insolation and the absence of any ter-action, there has accumulated an abundance of detrital oducts on the dry uplands and valleys forming a peculiar id of mantle-rock or regolith of fresh, undecomposed k-fragments. With the exception of a part of Ladakh, ich consists of Tertiary rocks and a basin of Mesozoic limentary rocks on the northern flank of the Zanskar untains, by far the larger part of the inner mountains is nposed of igneous and metamorphic rocks—granites, isses and schists.

lleys.

n conformity with the peculiarities of the other Himalayan ers, briefly referred to in the chapter on physical features, great rivers of this area—the Indus, Jhelum, Chenab and-

Ravi—after running for variable distances along the strike of the mountains, suddenly make an acute bend to the south and flow directly across the mountains. Just at the point of the bend, a large tributary joins the main stream and forms, as it were, its upward continuation. The Gilgit thus joins the Indus at its great bend to the south ; the Wardwan joins the Chenab at its first curve in Kishtwar, and the Ans at its second curve plainwards, above Riasi. The Kishenganga meets the Jhelum at Domel, where the latter takes its acutest curve southwards before emerging into the Punjab. These transverse, inconsequent valleys of the Himalayas, as we have seen before, are of great importance in proving the antiquity of the Himalayan rivers, an antiquity which dates before the elevation of the mountain-system (see page 19). The configuration of the valleys in the Inner Himalayas of the Kashmir regions is very peculiar, most of the valleys showing an abrupt alternation of deep U-shaped or I-shaped gorges, with broad shelving valleys of an open V-shape. This is due to the scanty rainfall, which is powerless in eroding the slopes of the valley where they are formed of hard crystalline rocks and where the downward corrasion of the large volume of streams produced by the melted snows is the sole agent of valley-formation. The broad valleys which are always found above the gorge-like portions are carved out of soft detrital rocks which, having no cover of vegetation or forest growth to protect them, yield too rapidly to mechanical disintegration. Many of the valleys are very deep. By far the deepest of all is the Indus valley in Gilgit, which at places is bordered by stupendous precipices 17,000 feet in height above the level of the water at its bed. That this enormous chasm has been excavated by the river by the ordinary process of river-erosion would be hard to believe were not the fact conclusively proved by the presence of small terraces of river gravels at numerous levels above the present surface of its waters.

The transverse valleys.

The configuration of the valleys

Lakes.

There are very few lakes in Kashmir, contrary to what one would expect in a region of its description. The few note-

worthy lakes are, the Wular in the valley ; the Tsomoriri in Rupshu, which is 15 miles long and 2 to 5 miles wide and about 15,000 feet high ; the Pangkong in Ladakh, which is 40 miles long, 2 to 4 miles wide and 14,000 feet in elevation The origin of the two last-named lakes is ascribed by Drew to the damming of old river courses by the growth of alluvial fans or dry-deltas of their tributary streams across them. These lakes have got several high-level beaches of shingle and gravel resting on wave-cut terraces marking their successive former levels at considerable heights above the present level of the water There are a number of smaller lakes or tarns, both in the valley of Kashmir proper and in the bordering mountains, most of which are regarded as true rock-basins.

Glaciers.

In Drew's work, already mentioned, there is a snow-map of Kashmir which admirably shows the present distribution of glaciers and snow-fields in the Kashmir and the adjacent regions With the exception of a few small glaciers in the Chamba mountains, there are no glaciers in the Middle and Outer Himalayas at present. In the Zanskar range glaciers are numerous though small in size , only at one centre, on the north-west slopes of the towering Nanga Parbat (26,000 feet), they appear in great numbers and of large dimensions. One of these (the Dayamir) descends to a level of 9400 feet above the sea, near the village of Tarshing. North and north-east of these no glaciers of any magnitude occur till the Hunza valley on the south of the Mustagh, or Karakoram, range is reached, whose enormous snow-fields are drained by a number of large glaciers which are among the largest glaciers of the world. The peak of K_2, on the southern side of this stupendous mountain chain, nourishes a number of gigantic glaciers some of which, the Biafo, the Báltoro and the Braldu glaciers, are only exceeded in size by the great Humboldt of Greenland There are two classes of these glaciers : those which descend transversely to the strike of the mountains and those which descend in longitudinal valleys parallel to the trend of the mountains. The latter are of large dimensions

Transverse and longitudinal glaciers.

and are more stable in their movements, but terminate at higher elevations (about 10,000 feet) than the former, which, in consequence of their steeper grade, descend to as much as 8000 to 7000 feet. The Biafo glacier of the Shigar valley reaches nearly 40 miles in length and the Hispar 25 miles The lowest level to which glaciers descend in the Kashmir Himalayas is 8000 or even 7000 feet, reaching down to cultivated grounds and fields fully 4000 feet lower than the lowermost limit of the glaciers in the eastern Himalayas of Nepal

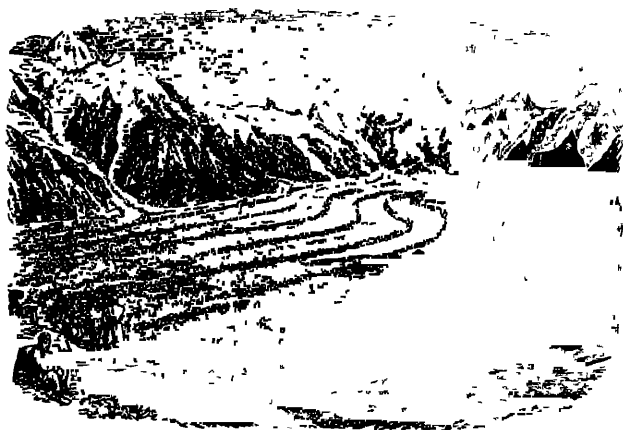



FIG 30 —View of the great Báltoro Glacier (From a drawing by Col Godwin Austen)
Woodcut from *Rudiments of Physical Geography for Indian Students*, by H F Blanford (1908) (Macmillan, London)

and Sikkim Many of these glaciers show secular variations indicative of increase or diminution of their volumes, but no definite statement of general application can be made about these changes. The majority of them, like the Tapsa, are receding backwards, leaving their terminal moraines in front of them, which have become covered by grass and in some cases even by trees; but others, like the Palma glacier, are steadily advancing over their own terminal moraines.[1]

Proof of Pleistocene Ice Age

There are abundant evidences, here as everywhere in the Himalayas, of the former greater development of glaciers,

[1] For glaciers of the Hunza valley, see *Rec G S I* vol xxxv pts 3 and 4, 1907

ılthough there are no indubitable proofs of their ever having descended ;o the plains of the Punjab, or even ;o the lower hills of the Outer Hima-ayas. Large transported blocks are frequently met with at various ocalities, at situations, in one case, out little above 4000 feet. The Jhelum valley between Uri and Baramula contains a number of large oulders of granitoid gneiss brought rom the summit of the Kaj Nag ange (to the N.W.), some of which re as large as cottages. In the ind valley, near the village of Hari 6500 feet) on the road to Sona Marg,)rew has seen a well-grooved *roche ıoutonnée.* A little higher up, at ona Marg itself (9000 feet), he escribes undulating valleys made p entirely of moraines. In the alley of Kashmir proper some of the ne impalpable buff-coloured sands, ıterstratified among the Karewa eposits, are regarded by some ob-ervers to be glacial mud ("rock ıeal") The whole north-east side f the Panjal range and to a less xtent elevations above 6000 feet on ıe south-west are covered thickly nder an extensive accumulation of ld moraine materials, which have uried all its solid geology (see Fig. l). In northern Baltistan, where ıe existing glaciers attain their aximum development, there are ,her characteristic proofs of old aciation at far lower levels than the west limits of modern glaciers;

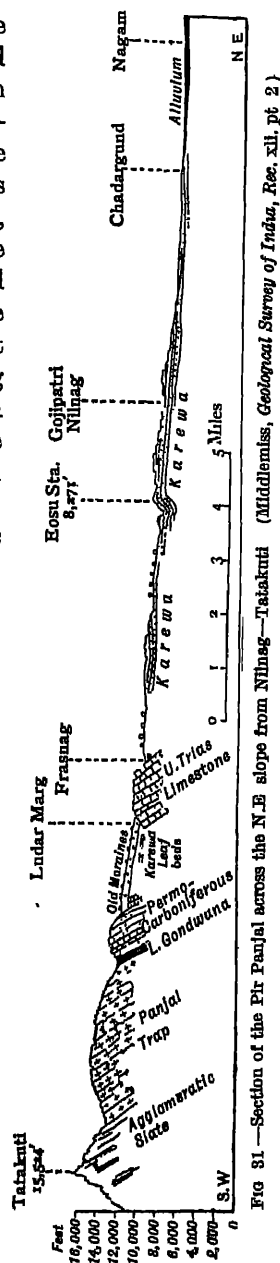



Fig 31 —Section of the Pir Panjal across the N.E slope from Nilnag—Tatakuti (Middlemiss, *Geological Survey of India, Rec.* xli, pt 2)

polished rock surfaces, rock-groovings, perched-blocks, etc., occur abundantly in the Braldu valley of this district. Many of the valleys of this region in their configuration are of a U-shape, which later denuding agencies are trying to change to the normal V-shape.

Desiccation of lakes

The well-marked desiccation of the lakes of Skardu, Rupshu and the other districts of north and north-east Kashmir, is a very noteworthy phenomenon and has an important bearing on this question The former higher levels of their waters point to a greater rainfall and humidity connected with the greater cold of a glacial period. The Tsomorırı has a terrace or beach-mark at a height of 40 feet above the present level of its waters. The Pangkong lake has similar beaches at various levels, the highest being 120 feet above the surface of the present lake.

STRATIGRAPHY OF KASHMIR

Introduction

The late Mr. R. Lydekker, forty-five years ago, made a geological survey of Kashmir. His results were published in a *Memoir* of the Geological Survey of India (vol xxii. 1883). Since 1908 Middlemiss has been working in the same field While the progress of his investigation has upheld some of Lydekker's conclusions, it has altered others, and at the same time brought to light a mass of facts which is new knowledge Lydekker in his preliminary survey grouped all the stratified formations of Kashmir into three broad divisions—the Panjal, the Zanskar and the Tertiary groups—the homotaxial relations of whose constituent series and systems were not clearly distinguished because of the absence of satisfactory fossil evidence. Middlemiss's researches have revealed a series of fossiliferous strata, in different parts of the province, belonging to various divisions of the Palaeozoic and the Mesozoic, which have enabled him to make a more perfect classification of the Kashmir record. Thus he has resolved what was formerly one comprehensive group, the Panjal system, which encompassed almost the whole of the Palaeozoic sequence, into no less than seven well-defined systems or series, the representatives of the Cambrian, Ordovician, Silurian, Devonian,

Carboniferous and Permian, and the homotaxial equivalents of those of the classic ground of Spiti.

This is a very good example of the way in which geological research has progressed in India In the earlier surveys, where a great extent of new ground has to be gone over in an unknown district or province, and where the affinities of the different rock-groups with known horizons are not perceptible, the strata are provisionally grouped into a few broad systems; these are further sub-divided into smaller divisions, by the help of local unconformities or gaps discernible in them, and all these newly discovered units, the major groups as well as the minor divisions, are named after the localities in which they are found, their relationships with the standard units being remotely indicated by such terms as *Older Palaeozoic*, *Carbon-Trias*, *Tertiary*, *Pre-Tertiary*, etc. In the later more detailed and exact surveys, the identity with stratigraphical units of adjacent, better-known areas is recognised, a more detailed classification, on a more natural basis, is rendered possible by the accumulated fossil evidence, and by these means the different sub-divisions are more or less precisely correlated to previously studied rock-groups of the other parts of the country. On this being accomplished, the smaller local names are discarded and a better and more comprehensive system of nomenclature adopted.

The account given in the following pages is deduced from the writings of Middlemiss and Lydekker. For more detailed information with regard to the whole of the Palaeozoic group and the Triassic system, the student should consult Dr. Middlemiss's original publication, *Rec. G S I.* vol xl. part 3, 1910. For the remaining systems, especially the Tertiary and later formations of Kashmir, the present writer's work in the Poonch and adjacent terrains should be consulted.[1]

[The geographical disposition of the main sedimentary belt in the Kashmir Himalayas calls for an explanation. While in the rest of the Himalayas the zone of marine sediments is wholly beyond, *i.e.* north of, the crystalline axis, in the Kashmir portion the most important sedimentary basin lies between two bifurcations of that axis, and in this way effaces that distinction between the

[1] D N. Wadia, "Geology of Poonch and Adjacent Areas," *Mem. G.S.I.* (in the press).

	Kashmir.	Spiti.	Salt-Range.	Age.
Aryan Era.	Low-level alluvia of Jhelum and Indus.	—	Loess deposits	*Recent*
	Pebble-beds of Jammu. *Upper Karewas* Lacustrine, fluviatile, and glacial alluvia. *Lower Karewas*	Older alluvium of the Sutlej		*Pleistocene*
	Upper Siwalik *Middle Siwalik* *Lower Siwalik* } 10,000 ft.	—	Upper *Siwalik* Middle *Siwalik* Lower *Siwalik*	*Pliocene* *Upper Miocene.* *Middle Miocene*
	Murree series, 5000 ft. { *Upper Murree.* *Lower Murree.*	—	—	*Lower Miocene.*
	Subathu series, Ranikot and Laki (300-1000 ft.) of Pir Panjal. *Indus Valley Tertiaries* of Ladakh.	*Nummulitics* of Hundes	*Nummulitic limestone* *Kirthar* series	*Eocene.*
	Chikkim limestone.	{ Flysch *Chikkim* series. *Giumal* series	Cretaceous beds of West Salt-Range	*Cretaceous.*
	Jurassic (very thick) { *Spiti shales.* *Tagling* stage (*Megalodon limestone*). *Para* stage.	*Spiti shales* *Kioto* limestone	Upper and Middle Jurassic of the West Salt-Range	*Jurassic.*
	Trias { Upper Trias Many thousands. Muschelkalk, 900 ft. Lower Trias, 300 ft.	Trias (*Lilang system*)	— Muschelkalk. *Ceratite* beds	*Triassic.*
	Zewan series, 300 ft.	*Productus shales*	*Productus limestone*	*Permian*
	Lower Gondwanas { Partly metamorphosed sandstones and shales (many thousand ft.) *Gangamopteris* beds (800 ft.)	Permian conglomerate	*Speckled sandstone* *Boulder-bed*	*Permo-Carboniferous.*

	Kashmir	Spiti.	Salt-Range	Age.
Dravidian.	*Panjal Traps.* *Panjal agglomerate-slates* Several thousand ft.	Unconformity		
	Fenestella series, 2000 ft.	*Po* series.	—	*Middle (?) Carboniferous*
	Syringothyris limestone series, 1000 ft.	*Lipak* series.	—	*Lower Carboniferous*
	Muth quartzites, 3000 ft	*Muth* series.	—	*Devonian.*
	Fossiliferous Silurian beds, 100 ft, underlain by obscurely fossiliferous Ordovician strata of great thickness.	Fossiliferous Silurian and Ordovician series of beds	—	*Silurian*
	Cambrian (?) greywackes and slates underlying fossiliferous Silurian beds. Panjal slate series of the Pir Panjal (Pre-Cambrian).	*Haimanta* system	*Salt-pseudomorph* shales. *Magnesian sandstone.* *Neobolus* beds *Purple sandstone.* *Red Salt-marl* (?)	*Cambrian.*
Archaean.	Archaean gneisses and schists, "*Central Gneiss*" of the Zanskar ranges, and of Baltistan, Gilgit, etc. Intrusive granites.	Gneisses and schists, with intrusive granites.	—	*Archaean.*

'Himalayan" and "Tibetan" zones so clearly marked in the other parts of the mountains

The distinction between the middle (Himalayan) and the outer (Sub-Himalayan) zones is, however, as clearly observable in this as in the other parts of the Himalayas.

In the province of Hazara this confusion between the three Himalayan stratigraphic zones is still more marked]

The table on pp 346, 347 gives an idea of the geological record as exposed in Kashmir.

THE ARCHAEAN SYSTEM

"Central Gneiss."

The crystalline complex. "Central gneiss."

Crystalline metamorphic rocks, gneisses and schists occupy very large areas in Kashmir to the north of the Outer Himalayas, forming the core of the Dhauladhar, the Zanskar and the ranges beyond, in Ladakh and Baltistan. These were called "central gneiss" by Stoliczka, and were all regarded as Archaean in age Later investigations, especially those of General MacMahon, have proved that much of this gneiss, as is the case with the whole of the Himalayas, is not of Archaean age, but is of intrusive origin, which has invaded rocks of various ages at a number of different geological periods. Also a great part of the crystalline schists and gneisses may be regarded as highly metamorphosed sedimentary formations of later ages. It is, however, very difficult to separate these different elements of the great basement complex—the truly Archaean gneisses and schists (the representatives of the Archaean system of the Peninsula)—from the granitic intrusions and the metamorphosed sediments. The gneisses have assumed a coarse granitoid aspect, while, owing to extreme dynamic metamorphism, the very much later intrusive granites have developed a gneissose or schistose structure.

Petrology.

In composition the gneiss often resembles a granite; and in a few cases, where the foliation is rudely developed, it resembles it in structure as well. Pink-coloured orthoclase is rare, so is also muscovite; the main mass of the gneiss being made up of milk-white felspar with quartz and a very conspicuous quantity of biotite, arranged in schistose or

lenticular manner, the foliation being fine or coarse This biotite gneiss is the most prevalent Himalayan gneiss from Kashmir to Assam It is a coarse, often porphyritic, gneiss, with phenocrysts of orthoclase as large as two inches, giving rise sometimes to an apparent *Augen*-structure. At times its place is taken by hornblende-gneiss. Accessory minerals are not common, except garnet Chlorite is often found replacing both biotite and hornblende. The felspar is generally deeply kaolinised. The gneisses are traversed by numerous veins of true intrusive granite, varying from a foot to as much as twenty feet in breadth, which in some cases penetrate the overlying sedimentary strata also. These intrusive veins show a greater divergence in their composition than the main mass which they traverse, often carrying, besides the ordinary constituents, such minerals as oligoclase, microcline, quartz, muscovite, tourmaline (both the black variety, schorl, and the coloured transparent varieties, rubellite and indicolite); also occasionally beryl (aquamarine), fluor-spar, garnet, corundum, sapphire, etc. Next to gneiss, the most usual rock is biotite-schist, passing into fine, thinly foliated, silky schists, such as hornblende,- chlorite-, talc-, muscovite-, etc Phyllites are also abundant with well-developed foliation planes, puckered or wavy.

Distribution

With regard to the distribution of the gneissic rocks in the Kashmir area, the main crystalline development is in the north and north-east portions of the State, while in the ranges to the south of the valley they play but a subordinate part. The core of the Dhauladhar range is formed of these rocks, but they are not a very conspicuous component of the Pir Panjal range, where they occur in a number of minor intrusions. The trans-Jhelum continuation of this range, known as the Kaj Nag, has a larger development of the crystalline core. A broad area of Kishtwar is also occupied by these rocks. But a far more extensive development of the crystalline schists is in the Zanskar range and in the region lying beyond it to the north It is from the circumstances of the prominent development of the crystalline core in this range, its continuity with the central Himalayan axis, that the Zanskar range is regarded as the principal continuation of the

Great Himalayan chain, after its bifurcation at Kangra. The other branch, the Pir Panjal, is regarded only as a minor offshoot. North of the Zanskar the outcrop of the crystalline series becomes very wide, encompassing almost the whole of the region up to Karakoram, with the exception of a few sedimentary tracts in the central and south-east Ladakh. The component rocks over all these tracts are gneisses and mica-, hornblende-, chlorite- and talc-schists with copious intrusions of granitic veins and masses. In the west and north-west of Baltistan, Gilgit and the adjoining districts, the Archaean, or, at any rate, the crystalline metamorphic rocks attain again an enormous development.

PALAEOZOIC GROUP

Ellipse of Palaeozoic rocks.

Fossiliferous Palaeozoic rocks of Kashmir occupy an elongated ellipse-shaped patch of the country north of the alluvial part of the valley, stretching from the Lidar to the south-east end of the Kashmir sedimentary "basin," where it merges into the Spiti basin. The long axis of this ellipse, north-west to south-east, corresponds to the axis of a broad anticlinal flexure, in which the

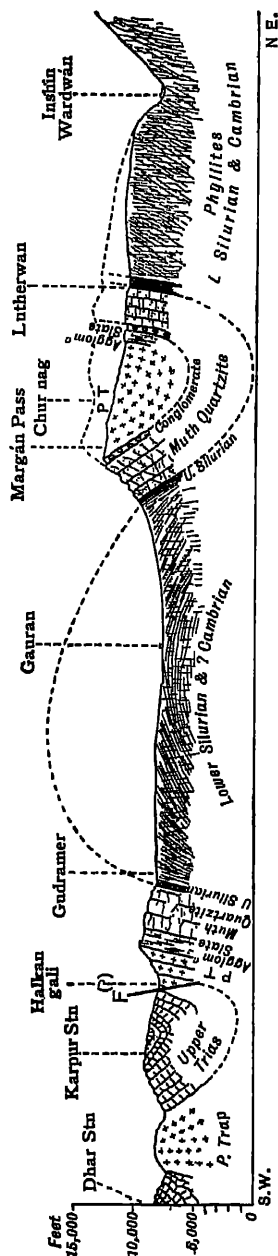



FIG 32.—General section, Nanbug Valley, Margan Pass and Wardwan to show the disposition of the Palaeozoic rocks of Kashmir (Middlemiss, *Rec G.S I* vol xl, pt 3)

whole series of Palaeozoic rocks is folded. Denudation has exposed, in the central part of this anticlinal, a broad oval outcrop of the most ancient fossiliferous rocks of Kashmir—the Cambrian and Ordovician—flanked on its two sides successively by thinner bands of the younger formations, Silurian, Devonian and Carboniferous (see Pl. VIII) Palaeozoic ›ocks, especially of the younger systems, are also conspicuous n the Vihi district and, to a less degree, on the Pir Panjal, vhile the great series of volcanic rocks of Upper Carboniferous ›ge are quite ubiquitous in their distribution over the whole ›rea of Kashmir, forming the main mass of the Panjal range nd of the smaller hills bordering the valley to the north and orth-east But the above-noted Palaeozoic area is the most

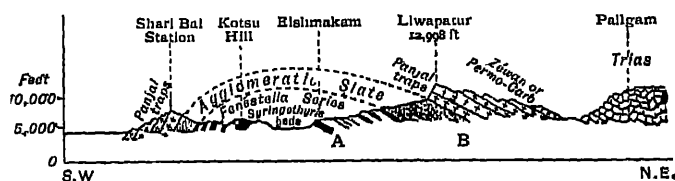



FIG 33 —Section across Lidar valley anticline
(Middlemiss, *Rec Geological Survey of India*, vol xl. pt 3)

ustrative and typical, and comprises, within a small geoaphical compass, the records of a large section of the ological history of the Kashmir region. This area is of rther importance as illustrating the simplicity of structure this part of the Himalayas.

Tho ellipsoidal patch that has resulted by the denudation the anticline is transversely dissected by the Lidar valley, ɔ of the most favourite routes of the Kashmir tourist, ding to the hill-station of Pahlgam or the famous ice-cave Amar Nath. At places, not very remote from the main ɏ, good natural clear sections of the rock-systems of Kashmir to be seen, with several fossiliferous localities, from ch collections can be made and sketches illustrating relations of the various series obtained. Another good ural section of the Palaeozoic succession is to be seen along course of a small stream, the Arpat river, by a way leading ı Achabal to the Hairbal Galli.

The student must constantly have before him the topographic map of Drew and also the smaller but more useful geological map by Middlemiss published in *Rec.* vol. xl. part 3, reproduced in Pl XIII.

CAMBRIAN ? AND ORDOVICIAN

Distribution.

The rocks of these ages occupy a rather extensive tract in the shape of an oval in the middle of the anticlinal arch referred to above (see Fig. 32). A conformable passage can be traced from fossiliferous Silurian strata to a thick group of beds below, from which circumstance and from the evidence of their distinctly sedimentary origin, Middlemiss has ascribed to them a Lower Silurian or Ordovician age, attributing a still older (Cambrian) age to a group of strata lying conformably below the latter. Conclusive fossil evidence is lacking in respect of the group of strata assumed as Cambrian, but obscure organic remains characterise the higher beds for which an Ordovician age is claimed with better justification; *e.g.* at Hundwara a buff slate is full of *trilobites*, casts and impressions.

Composition.

In composition the rocks are thin-bedded argillaceous, siliceous and micaceous slates, often interbedded with compacted arenaceous and calcareous beds, recalling, in their peculiar lithology, the rocks known as *greywackes* in England. They are of a dull, grey monotonous colour. An imperfect cleavage is observed in them which sometimes approaches to an incipient schistosity. In the Wardwan valley the greywackes and slates have developed a distinctly phyllitic or schistose aspect owing to the metamorphism brought about in them by granitic intrusions.

Geological structure

In their structural relations, the greater part of these oldest sediments show but little evidence of any contortion or overfolding; on the other hand, they exhibit quite a simple structure. They have shared in the general anticlinal folding of rocks of the district, the dips being rather high on the south-west side of the anticlinal, approaching to verticality near the south-east end (at Gudramer).

In the Wardwan valley the same rocks reappear by a syn-
inal bending underneath the younger strata of the intervening
act of ground.

SILURIAN

Round the oval expanse of the rocks just described, there **Distribution.**
is a thin but continuous band of unmistakable Silurian
ata, from which well-preserved Silurian organisms have
en obtained. These rocks are continuously met with on
north-east side of the anticlinal from the neighbourhood
Eishmakam in the Lidar valley to Lutherwan in the
rdwan valley. On the south-west flank the outcrops are
as continuous, being hidden under the recent alluvium of
Lidar and Arpat streams and their tributaries.

ithologically the strata bear close resemblance to the **Rocks.**
erlying Cambrian and Ordovician, being composed of
ly shales or shaly sandstones with impure yellow limestones,
they are distinguished by the presence of a well-preserved
of fossil organisms. Limestones and calcareous rocks
less common than in the corresponding rocks of Spiti.
aggregate thickness of the fossil-bearing Silurian strata
nly 100 feet, but the organisms preserved in them
no doubt of their age, thus denoting a highly valued
gical horizon in India. They offer one of the few
ices, in the whole of the Indian region, where a well-
d Silurian fauna occurs. The student should here
d himself that a fossiliferous Silurian horizon exists in
entral Himalayas above the Haimanta system of Spiti
n the neighbouring area of Kumaon and Garhwal; a
l example is the Shan States of Upper Burma. The
ence of Silurian rocks is suspected, on strong litho-
grounds, in Hazara and farther west in Chitral, but
sil has been obtained from these localities hitherto,
eir definite correlation is a matter of doubt.

1

principal fossil is *Orthis*, which occurs in a large number **Fossils**
es. Other Brachiopods belong to the genera: *Leptaenia*,

er Reed: "Silurian Fossils from Kashmir," *Rec.* vol. xlii. pt. 1.

Strophodonta, Atrypa, Meristella, Crania, Strophomena, Conchidium.

Of Trilobites the following genera occur. *Calymene, Illaenus, Phacops, Acidaspis, Encrinurus, Beyrichia*

The Cephalopods are represented by *Orthoceras* and *Cyrtoceras.*

Some corals, among which are *Alveolites, Petraia* or *Lindstraemia.*

The absence from this fauna of the well-known Silurian corals like *Favosites, Heliolites, Cyathophyllum, Syringopera,* etc., which are present in the homotaxial deposits of Spiti, is noteworthy. The evidence of the other fossils, however, points to a similarity between these two deposits, a correspondence borne out by all other subsequent formations.

DEVONIAN

Occurrence. The Devonian of Kashmir comes conformably on the group last described. Its outcrop follows the outcrop of the Silurian in normal stratigraphic order and is co-extensive with the latter. Devonian strata are well seen on both the flanks of the Lidar anticlinal as thin bands; they are also well exposed in the Wardwan district, where their re-appearance is due to a synclinal folding.

Petrology. The rocks regarded as Devonian are a great thickness of massive white quartzites. This rock, both in its composition and texture as well as in its stratigraphic relations to the rocks below and above it, exactly resembles the Muth quartzite of Spiti and Kumaon, which has been regarded as Devonian. As in Spiti, these massive beds of quartzite, reaching the enormous thickness of 3000 feet at places, are totally devoid of any fossil-remains. The inference of their age, therefore, is solely based on their stratigraphic position: the Muth quartzites rest normally between fossiliferous Upper Silurian beds below and fossil-bearing Carboniferous beds above, whose fossil organisms indicate Lower Carboniferous affinities; it is, therefore, reasonable to infer that the Muth quartzites are Devonian in part at least Such evidence, however, cannot be quite decisive, and it is possible that part or

whole of the Muth quartzite series may ultimately prove to be of either of those ages—Upper Silurian or Lower Carboniferous or both. Outcrops of the Muth series are easily detected by the prominent escarpments and cliffs which it forms, due to the harder and more compact quartzites resisting the action of the denuding agencies better than the underlying slates.

LOWER CARBONIFEROUS

Syringothyris Limestone Series.

Distribution.

Next in the order of superposition is a series of limestone strata lying conformably over the Muth quartzites. The outcrop of this limestone forms a thin band bordering the north-west half of the ellipse we are considering; it cannot be traced further eastwards, being to a great extent hidden under superficial deposits such as river alluvia. It has also suffered greatly by the overlapping of the Panjal traps, which approach t from the north by successively overlapping the younger eries The present series is well exposed at Eishmakam and Kotsu, which are good localities for collecting fossils.

Lower Carboniferous fossils.

The rocks composing the Lower Carboniferous of Kashmir re mainly thin-bedded flaggy limestones of a grey colour. The calcareous constitution of this series readily distinguishes from the older series, which are devoid of strata of limestone. The limestones are crowded with fossils principally elonging to the brachiopod class. The most frequently ccurring brachiopod, which characterises the series, is *yringothyris cuspidata*. This is a valuable index fossil, eing also very typical of the Lipak series of Spiti. *Chonetes* found in large numbers, together with many species of *Productus*, of which the species *P. cora* is the most common, while . *scabriculus* and *P. reticulatus* are not so abundant. *Athyris*, *erbyia* and *Rhynchonella* are among other brachiopods.

The age of the Syringothyris limestone series is determined that of the Lipak series, with which it shows exact rallelism. From the association of *Syringothyris cuspidata* th species of Trilobites (*Phillipsia*), regarded as Lower rboniferous, in the Lipak group of Spiti, Hayden has ribed to that group a Lower Carboniferous horizon.

MIDDLE (?) CARBONIFEROUS

Fenestella Shales.

Passage beds. Overlying the upper beds of the Syringothyris limestone there comes some thickness of unfossiliferous quartzites and shales before the first beds of the characteristic Fenestella-bearing strata begin. These intermediate beds in their composition are allied to the upper group—the Fenestella shales to be presently described—but since they contain no fossils proper to that series, they are regarded as "passage beds" between the two series

Distribution. In distribution this group is even more restricted than the last-described, being confined only to the north-west part of the ellipse of Palaeozoic rocks where it broadens out in an expansive outcrop overspreading the country around Lehindajjar to the left side of the Lidar valley. To the south-west the series is totally missing, having been obliterated by the overlap of the Panjal lavas. On the north flank of the anticlinal, the outcrop stops short at the Hairbal Galli, while on the south it does not appear at all.

Lithology Lithologically the Fenestella shales are a great thickness (more than 2000 feet) of thickly bedded quartzites interstratified with blackish shales. The shales are more prevalent at the base, becoming scarce at the middle and top. The shales are the only fossil-bearing horizons in the series, being rich repositories of fossil polyzoa—*Fenestella*, which gives the name to the series—brachiopods, corals and lamellibranchs.

The following is a characteristic section seen at Lehindajjar:

	Panjal conglomerate-slates.	Upper Carboniferous.
Fenestella shales.	Uppermost Fenestella shales, not thick	Middle Carboniferous. (?)
	Unfossiliferous quartzites and shales, 500-600 ft.	
	Black sandy shales with *Fenestella*, 100 ft.	
	Quartzite, 60 ft.	
	Greyish shaly sandstone, obscure fossils, 200 ft.	
	Dark shales full of *Fenestella*, corals, brachiopods, lamellibranchs, 150 ft.	
	Quartzite, 100 ft.	
	Sandy shales, full of Productus and other fossils, 500 ft.	
	Base not seen.	

The most abundant fossils are casts, often ferruginous, of ·ecies of *Fenestella*, the impressions of whose fan-shaped aria are preserved in countless numbers, often in great ·rfection. Brachiopods are also abundant in number as well in species. The most commonly occurring are: *Spirifer* (*S iddlemissii* and *S Varuna*), *Productus undatus*, *P. cora*, *hdarensis*, *P Spitiensis*, *P. scabriculus*, *Dielasma*, *Uncinella*, *ilosteges*, *Camarophoria*, *Rhynchonella*; the lamellibranchs are: *odiola* and *Aviculopecten*; some pygidia of *Phillipsia*. Besides *nestella* another polyzoon, though very rare, is *Protoretepora*. e two must be carefully distinguished, for the latter genus aracterises a younger series of beds which lies over the njal trap series.

Fauna

Γhe fauna of the Fenestella series possesses, according to Diener, strikingly individual characters of its own. Many the fossil forms are quite special to it, bearing no relations any definite Carboniferous horizon. For this reason their atigraphic position is dubitable, and may be any between wer and Upper Carboniferous according to the same hority.[1]

Age of the Fenestella series

:he disposition of the outcrops of the Fenestella shales eals the existence of a dip-fault traversing it along the ar basin. The actual fault is not seen, but its effect upon outcrop on the two banks of the river is quite apparent. › exposure on the left bank lies much higher up the river n the right bank outcrop. This is in consequence of a ·ral shift (heave) produced by a fault cutting across the ke of the beds

UPPER CARBONIFEROUS

› Panjal Volcanic Series.

gglomerate Slates and Traps.—During the last stage of the ›sition of Fenestella shale-beds, the physical geography of Kashmir area underwent a violent change, and what was re a region of quiet marine sedimentation was converted a great theatre of vulcanicity, whereby an enormous ·rficial extent of the country was converted into a volcanic

Middle Carboniferous earth movements.

[1] Diener, *Pal. Indica*, vol. v. mem. 2, 1915, New Series.

region, such as Java and Sumatra in the Malay Archipelago of the present day. The clastic and liquid products of these volcanoes buried large areas of Kashmir under thousands of feet of lavas and tuffs. The volcanic activity was most intense during the Upper Carboniferous when it reached its climax, after which it diminished greatly, though at isolated centres it persisted up to the Triassic period

Physical history at the end of Dravidian era.

The earth-movements and physico-geographical revolutions with which this igneous outburst was associated in the Kashmir area, were connected and contemporaneous with the crust-movements in other parts of India at the end of the Dravidian era. This was the epoch of many far-reaching changes on the face of India, as we have seen in Chapter VIII. These changes introduced a temporary continental phase in Kashmir succeeding the Dravidian marine period and preceding the Aryan geosynclinal period. In the interval of this land epoch Gondwana conditions invaded Kashmir, converting it in fact into a north-western province of that continent. As the volcanic fires quieted down, the fern and conifer, the fish and amphibian migrated from the south-east lands and peopled Kashmir

This land epoch in the history of Kashmir was, however, of but short duration. For the sea soon resumed its hold over this area in the Permian times and commenced to throw down its characteristic deposits on the geosynclinal of the Tethys, which once more brought Kashmir within the "Tibetan" zone of the Himalayas. The Permian of Kashmir, as we shall see, is both in its physical and biological characters on a par with the Productus limestone of the Salt-Range and the Productus shales of Spiti and other Himalayan areas.

Panjal Volcanic Series.

Rocks of this series are divisible into two broad sections: the lower—a thick series of pyroclastic slates, conglomerates and agglomeratic products, some thousand feet in thickness, and called by Middlemiss the "Panjal agglomeratic slates"; and the upper—the "Panjal traps," an equally thick series of bedded andesitic traps generally overlying the agglome-

rates. The series covers an enormous superficial area of the country, being only next in areal distribution to the gneissic rocks.

Distribution.

It is specially well developed in the Panjal range, of which it forms the principal substratum, being visible as prominently on its sides and summit, as in its centre, for the entire length of the range from the Jhelum to its termination at the Ravi (see Pl XV.) This circumstance gives the name Panjal to the series. They also form the black hill-masses on the north-west continuation of the Zanskar range, beyond Nun Kun to as far as Hazara. The Panjal slates and volcanics are also developed in Ladakh, extending further to the north-east in the direction of the Changchenmo valley to the very farthest borders of the Kashmir territory. A few outliers of the same rock are met with in Baltistan as far north as Skardu.

The stratigraphical position of these deposits is noteworthy. They come between the two great series of marine fossiliferous deposits—the Dravidian and Aryan—and thus serve to fill up the gap represented elsewhere in India by a pronounced unconformity of deposition, representing a period of crust-movements and geographical revolutions

Nature of the Panjal slates.

The nature of slate-agglomerate.

The mode of origin of the lower part of the Panjal volcanic series, or what has been called the "agglomeratic" slates, is not easy to understand. Much of it is composed of a fine greywacke-like matrix with embedded angular grains of quartz But the rock does not appear to be an ordinary sedimentary deposit, inasmuch as the embedded fragments are quite angular and often become very large in size at random. They are pieces of quartz, porphyry, tourmaline-granite, slate, etc, irregularly dispersed in a fine-grained matrix. The rock is generally unfossiliferous throughout, though recently at a few localities several interesting suites of fossils have been discovered by Middlemiss and the late Mr Bion, which are identical with forms entombed in the underlying Fenestella series. That such a rock could not have been the product of any simple process of sedimentation, whether subaerial or submarine, is quite clear, and the origin of the deposit so widespread and of such uniform character is a problem.

One view is that the rock is a joint product of explosive volcanic action, combined with ordinary subaerial deposition; the other, a diametrically opposite view, is that it is due to frost-action under glacial or arctic conditions, the frost-weathered débris being subsequently transported by floating ice-masses to lakes. Middlemiss favours the former view, as being more in keeping with the actual circumstances of the case and as congruent with the lava-eruptions that succeeded it; though he points out that the absence of glass-particles, pumice fragments and other products usually associated with tuffs, is irreconciliable with this view. Late work in the Poonch Pir Panjal tends to establish the pyroclastic nature of parts at least of this formation beyond any doubt. The matrix of the slate often is full of devitrified and altered glass with phenocrysts of felspars. (Wadia, *Mem. G.S.I.* "Geology of Poonch.") The presence of Lower Gondwana plants in beds immediately overlying the volcanics favours the inference that the slate-conglomerate is a glacial deposit corresponding to the Talchir boulder-beds. No facetted or striated pebbles are, however, found in the slates, which, on the contrary, are frequently quite angular. The following section gives a general idea of the rocks of the Panjal series:

Aggregate thickness some thousand feet.	5. Bedded green and purple traps, several thousand feet thick. 4. Greenish slates and quartzites with amygdaloidal traps. 3 Black and grey agglomeratic slates with thick beds of conglomerate containing sub-angular pebbles of quartzite and slate. 2. Whitish quartzite and sandstones. 1. Black agglomeratic slates with angular or sub-angular pebbles of gneiss and quartz.

Panjal lavas

Over the agglomeratic slates there comes a great thickness of distinctly bedded massive lava-flows. In composition the lava is a basic variety of augite-andesite, of a prevailing dark or greenish colour, the green colour being due to the alteration of augite and other constituents into epidote. The rock is usually non-porphyritic and very compact in texture, but porphyritic varieties are sometimes, and amygdaloidal varieties are often, met with. In microscopic structure the lavas are a micro-crystalline aggregate of plagioclase felspar and finely

Petrology.

granular augite, with traces of yet undevitrified glassy matrix. Magnetite is very common in irregular grains and crystals. No olivine is present, nor any well-formed crystals of augite. The structure is hemi-crystalline throughout, only minute prisms of white turbid felspar being detected in a finely granular aggregate, but in some varieties there are large prismatic phenocrysts of felspar arranged in star-shaped or radiating aggregates giving rise to what is called *glomero-porphyritic* structure. Some varieties are amygdaloidal, the amygdales being composed of silica or epidote or some zeolites. The lavas often show widespread alteration of the nature of epidotisation and silicification Devitrification is most common. Green chlorite is commonly present in the felspars and epidote is a universal secondary product resulting from the interaction between augite and plagioclase.

When the lavas are interbedded with the slates, the contact metamorphism induced in both the rocks is of very intense degree, the two becoming quite indistinct from each other. At Gagribal, near Srinagar, such an intimate association of the two kinds of rocks is seen (resembling the *lit-par-lit* intrusion of the plutonic rocks).

The individual flows vary in thickness from a few inches to twenty feet or more, and are markedly lenticular. There are no sedimentary intercalated beds of the nature of "inter-trappean" beds. This shows that the eruptions succeeded each other with comparative rapidity and, therefore, the entire Panjal trap series represents a comparatively small interval of geological time. The total aggregate thickness of the lava-flows measures several thousands of feet. But this development is often purely local; over large areas the trap is missing, its place being occupied by agglomerate slate.

Age and vertical extension of Panjal lavas.

The upper limit of the Panjal lava-flows is usually clearly defined, being fixed by the directly overlying plant-bearing beds of Lower Gondwana (Talchir) facies, which in turn are immediately succeeded by marine Permian rocks. In one or two cases, however, the flows have been found to extend to a much higher horizon, as far as the Triassic, a few flows being found locally interbedded with limestone of that age. In

general the Panjal volcanoes ceased their eruptive activity at the beginning of the Permian. These subaerial volcanic eruptions therefore bridge over the gap which is usually perceived at the base of the Permian in all other parts of India.

In addition to lava-flows there are seen dykes and laccolithic masses of a gabbroid magma, cutting through both the Panjal slates and through the Fenestella shales in several parts of Kashmir.

LOWER GONDWANA BEDS

Gangamopteris Beds

Distribution. The Panjal traps are directly and conformably overlain in several parts of Kashmir by a series of beds of siliceous and carbonaceous shales containing the ferns *Gangamopteris* and *Glossopteris*, so eminently characteristic of the Talchir series of the Peninsular Gondwanas. The Gondwana plant-bearing beds have been met with at several localities, *e g.* on the north-east slopes of the Pir Panjal, where they overlie the traps and underlie the Permian and Triassic limestone They are also met with in the district of Vihi Of these, the exposures at Risin and Zewan in the Vihi district are the most noteworthy because of their directly overlying fossiliferous Permian strata, a circumstance which clearly establishes their exact stratigraphic horizon This is illustrated in the section in Fig. 34, p 365. This series of beds is known as the Gangamopteris beds from the most prevalent fern, impressions of whose leaves are well preserved in the black or grey shales. A fossiliferous outcrop of these beds is visible at the Golabgarh pass of the Pir Panjal, one of the passes on the range leading from the province of Jammu to Kashmir. Another is seen in a ravine (the Guryul ravine), near the village of Khunmu. The Gangamopteris beds are composed of a variable thickness of cherts, siliceous shales, carbonaceous shales and flaggy siliceous beds of quartzite The thickness varies from a few feet at some of the Vihi outcrops to some hundreds of feet in the outcrop at the Panjal range. A peculiar rock of this series is a "novaculite," well seen at Barus and at Khunmu. It is a compact

Lithology

chert-like rock of white or cream colour, which has replaced an original limestone by silicification, forming the base of the series and directly overlying the traps. The black shales of many of the outcrops of the Gangamopteris beds are likewise frequently silicified On the south-west flank of the Pir Panjal Gondwana beds constitute a thick series of fluviatile deposits some thousand feet in thickness consisting of partly metamorphosed shales, phyllites, quartzose grits and sandstones, the latter showing extensive ripple-marking, cross-bedding and colour-banding. The series is generally barren of recognisable fossils, but a few badly preserved impressions suggestive of plant as well as animal remains are helpful in supplementing the evidence of terrestrial origin and deposition of these sediments The section below gives he chief components of the series viewed at the Golabgarh Pass.[1]

The Golabgarh section.

Zewan series.	Protoretepora limestone.		Permian.
Gangamopteris beds	Earthy sandstones, calcareous above, passing into Zewan limestones.	230 ft.	
	Hard, compact black shales with *Glossopteris*, hard grey sandstones and interbedded shales with *Psygmophyllum*, *Gangamopteris* and *Vertebraria*	400 ft.	Lower Gondwana. (Permo-Carboniferous.)
	Thin-bedded, buff-coloured compact siliceous and carbonaceous shales.	180 ft.	
	Basal conglomerates.	6 ft.	
	Panjal traps and ash-beds.		Upper Carboniferous.

Fossils.

The Gondwana fossils comprise impressions of the leaves of ferns, equisetums, conifers, etc, together with parts of he skeletons of labyrinthodonts and fishes. The plants are hiefly obtained from the Golabgarh outcrop, while the vertebrate remains were obtained from Khunmu. The plants nclude a species of *Gangamopteris* sufficiently distinct from

[1] Middlemiss, *Rec. G.S.I.* vol. xxxvii. pt. 4, 1909. For another section t Zewan, see Hayden, *Rec. G.S.I* vol. xxxvi. pt. 1, 1908.

those of the Peninsula to be named *G. kashmirensis*. Other fossils are *Glossopteris indica*, *Vertebraria indica*, *Callipteridium*, *Cordaites* (resembling *Noggerathiopsis*) and leaves of *Psygmophyllum*, a conifer genus related to *Ginkgo* The vertebrate fossils consist of the scales, fins, portions of skulls, a mandible, and fragments of the hind-limbs of *Amblypterus* (a cartilaginous *ganoid* fish), together with fragmentary remains of a species of labyrinthodont *Archegosaurus*

Age.

The exact horizon represented by the Gangamopteris beds, in terms of the typical Gondwana sequence, is denoted by the types *Gangamopteris* and *Glossopteris*, the former suggesting the lower (Talchir) stage, the latter the upper (Karharbari) stage of the Talchir series. These plants, moreover, resemble the characteristic Lower Gondwana types of South Africa, Australia and other countries of the Southern Hemisphere, and are thus very interesting as affording us a glimpse into the geography of the northernmost limit of the Gondwana continent which comprised within its borders all these countries.

The association of the Lower Gondwana beds with marine strata below and above them (viz the Upper Carboniferous Fenestella shales and the Permian Zewan beds) is an event of the greatest importance in the stratigraphic records of India It has helped to solve one of the most difficult problems of Indian geology—the settlement of the precise horizon of the Lower Gondwana system of India.

THE PERMIAN

The Zewan Series.

The Zewan beds.

The Permo-Carboniferous series of deposits, the local representative of the Productus limestone of the Salt-Range and of the Productus shales of Spiti, makes a very well-marked horizon in the geology of Kashmir. These deposits have been known since an early date as the Zewan beds, from their exposure at the village of Zewan in the Vihi district. At this particular locality the Gangamopteris beds are overlain by a series of fossiliferous shales and limestones containing crowds of fossil brachiopods and polyzoa. In other parts of Vihi this series is more fully formed, the portion

epresentative of the typical Zewan section being succeeded by nother thick group of limestone and shales underlying the ower Triassic beds. The term "Zewan series" has conse- uently been amplified to receive the entire succession of eds between the Gangamopteris and the Lower Triassic beds. he base of the Zewan series is argillaceous in composition, ie shales being crowded with the remains of *Protoretepora*,

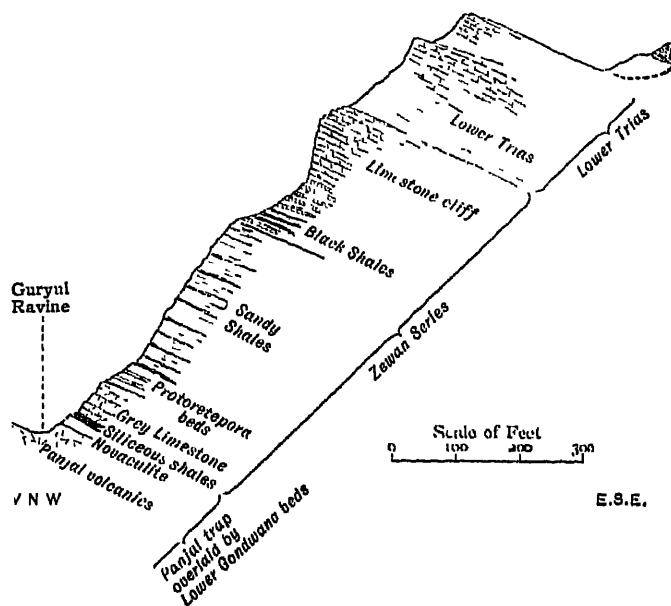



FIG 34 — Section of the Zewan series, Guryul Ravine. (Middlemiss, *Rec Geological Survey of India*, vol. xxxvii. pl 1.)

olyzoon resembling *Fenestella*. The upper part is cal- ous, the limestone strata preponderating. In a few shales rcalated among the latter, is contained a fauna resembling of the Productus shales of Spiti and other parts of the ral Himalayas. Over the top of the series there lie thin ls of hard limestone and shales bearing *Pseudomonotis*, *ubites* and other ammonites, marking a Lower Trias limit. thin but continuous band of Zewan rocks is seen along outh-west hills of Vihi, which is co-extensive with the more prominent Triassic outcrop. A few thin isolated

outcrops of the series are noticed in the Pir Panjal on either side of the central axis, overlying the trap.

The following section, very well exposed in a ravine near Khunmu (Guryul ravine), is reproduced from Middlemiss and Hayden:

Meekoceras zone of the Lower Trias.

Bed	Thickness
Shales and limestone, thin-bedded. Fossils: *Pseudomonotis, Bellerophon, Danubites, Flemingites*	100 ft.
Dark arenaceous shales, micaceous and carbonaceous, with limestone intercalations at base. Fossils: *Marginifera Himalayensis, Pseudomonotis*, etc	300 ft.
Shales and limestone, crowded with *Protoretepora, Athyris Royssii, Productus, Dielesma*, etc.	30 ft
Dark grey limestone with shale partings. Fossils. *Athyris, Notothyris*, etc.	60 ft

Novaculites and other siliceous strata of the *Gangamopteris beds.*

Fossils

Fossils are present in large numbers in the Zewan beds. They include one *Nautilus* and two genera of ammonites, *Xenaspis* and *Popanoceras*. The lamellibranchs are *Pseudomonotis*, *Aviculopecten* and *Schizodus*, but the most predominant groups are the brachiopods and polyzoa. The former are represented by *Productus cora, P. spiralis, P. purdoni, P. gangeticus, P. indicus, Spirifer rajah* (the most numerous), *Dielesma, Martinia, Spirigera, Spiriferina, Marginifera vihiana, M. himalayensis, Lyttonia, Camarophoria, Chonetes, Derbyi*, etc. Among polyzoa the species *Protoretepora ampla* is present in overwhelming numbers at some horizons. Its fan-shaped reticulate-structured zoaria resemble those of the *Fenestella*, but the former belongs to a slightly different zoological family. *Acanthocladia* also is a frequent form. *Amplexus* and *Zaphrentes* are the more common corals.

Age of the Zewan series.

From the palaeontological standpoint the Zewan series is correlated to the Permian system of Europe, a conclusion amply corroborated by the stratigraphic relations of the series to the Lower Trias. An interesting fact revealed by the Zewan fauna is the exact parallelism of these deposits with the middle and upper part of the Productus limestone of the Salt-Range, most of the genera and many of the species being common to the two regions. A comparison of the faunas with

he Productus (Kuling) shales of the Central Himalayas also
rings out the closest zoological affinities between these three
omotaxial members of the Indian Permian and Permo-
'arboniferous systems.[1]

TRIASSIC

The Trias of Kashmir, in common with the whole length of
ie North Himalayas from the Pamirs to Nepal, is on a scale
f great magnitude. A superb development of limestones and
olomites of this system is exhibited in a series of picturesque
carpments and cliffs forming the best part of the scenery
orth of the river The Trias attains great dimensions farther
orth in the upper Lidar valley, and again in Central Ladakh,
ence extending as far as the Karakoram and Lingzhithang
ains. Another locality for the development of the Trias,
incipally belonging to its upper division, is witnessed in the
r Panjal, of which it is the youngest constituent rock-group,
pping the Gondwana beds of the range over the whole stretch
the range from Toshmaidan to Golabgarh A great part
the Triassic rocks on the north-east flanks, however, are
scured under later formations such as the Karewas and
raine débris.

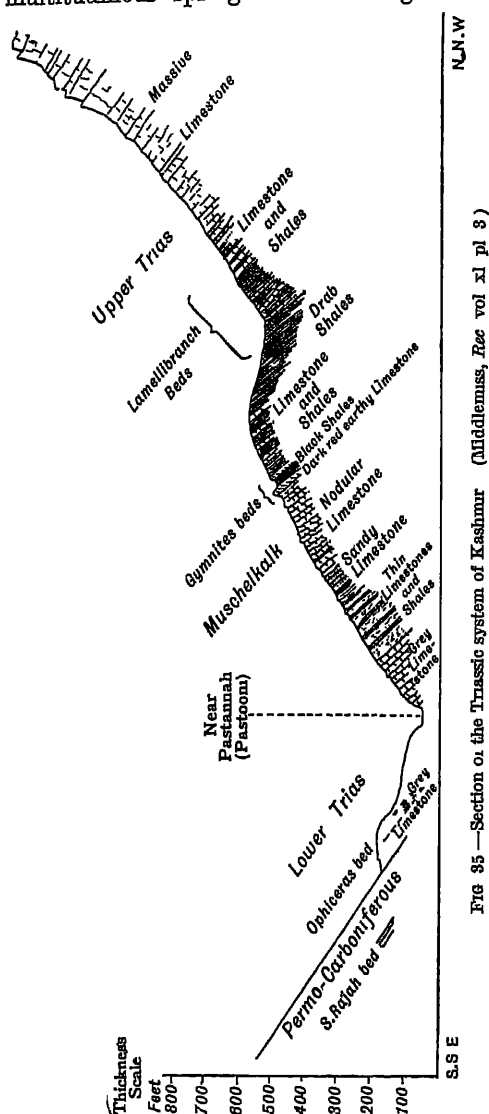
The Trias of Kashmir.

Limestones are the principal components of this system.
e rock is of a light blue or grey tint, extremely compact
d homogeneous, and often dolomitic in composition. They
thin-bedded in the lower part of the system, with frequent
erstratifications of calcareous shales, but towards the top
y become one monotonously uniform group of thickly-
lded limestones. They compose a very picturesque feature
the landscape, easily noticeable from all parts of the valley
the light colouration of their outcrops and their graceful
g and undulating folds, both of which characteristics
ig them out in strong relief against the dark-coloured,
ch contorted lavas and slates of the underlying Panjals.
nerous springs of fresh water issue from the cliffs and
minences of these limestones at the south-east end of the
ey, which form the sources of the Jhelum; the best known

Lithology.

[1] Dr Diener, *Pal. Indica* (New Series), vol. v. mem. 2, 1915.

of these are the river-like fountains of Achabal and Vernag and the multitudinous springs of Anantnag and Bhawan

FIG 35 —Section of the Triassic system of Kashmir (Middlemiss, *Rec* vol xl pl 3)

The lower and middle sections of the system are rich in fossils, the abundance of the Cephalopoda and the peculiarities of

heir vertical range in the strata being the means of a very letailed zonal classification of the system, all the zones of which are related to the corresponding ones of Spiti. The pper division of the Trias is almost, if not quite, barren f fossils. Middlemiss's explorations in this region have rought to light the following succession of the Triassic strata Kashmir:

pper Trias. (Many thousand feet thick)	Unfossiliferous massive limestone. *Spiriferina Stracheyi* and *S. Haueri* zones. Lamellibranch beds.
ischelkalk. (About 900 ft.)	Ptychites horizon: sandy shales with calcareous layers. *Ceratite* beds ,, ,, ,, ,, *Rhynchonella trinodosi* beds: ,, ,, ,, *Gymnites* and *Ceratite* beds: ,, ,, ,, Lower nodular limestone and shales. Interbedded thin limestones, shales and sandy limestones.
wer Trias. Over 300 ft.)	*Hungarites* shales (position uncertain). *Meekoceras* limestones and shales. *Ophiceras* limestones.

Lower Trias. At several points in the Vihi district, as already stated in last section, the Zewan series shows a conformable passage wards into a series of limestone strata, which in their fossil monites are the exact parallels of the *Ophiceras* and *Meekos* zones of Spiti. These in turn pass upwards, after the rvention of a shaly zone (the *Hungarites* zone), into the t succession of Middle Triassic limestones and shales. best sections of the Lower Trias are those laid bare at tanah and at Lam, two places on the eastern border of Vihi district, though the sections are somewhat obscured jungle-growth. Fossils: Ammonites, *Xenodiscus* (seven ies); *Ophiceras* (*O. Sakuntala* and five other species); *vingites*; *Vishnuites*; *Hungarites*; *Meekoceras*; *Sibirites*; a new genus of ammonite, *Kashmirites*. Other cephalopods *Orthoceras* and *Grypoceras*; the lamellibranch, *Pseudotis*, is a type form.

Middle Trias. ctions of the Middle Trias, or Muschelkalk, are visible at y points in Vihi, *e.g.* at Pastanah, Khrew and Khunmu. limestones of this part of the Trias are more frequently bedded with shales, the latter being often arenaceous,

The Muschelkalk has yielded a very diversified fauna of cephalopods indicating the very high degree of specialisation reached by this class of animals, particularly the order of the ammonites. The specific relations of the types are in all respects alike to those of the other parts of the Himalayas

The Muschelkalk fauna

The principal forms of the Muschelkalk fauna of Kashmir are *Ceratites* (sixteen species), *Hungarites, Sibirites, Isculites, Pinacoceras, Ptychites, Gymnites* (sp. *Sankara, Vasantsena* and other species), *Buddhaites.* The nautiloida are *Syringonautilus, Grypoceras, Paranautilus, Orthoceras* The lamellibranch genera are *Myophoria, Modiola, Anomia, Anodontophora*; the brachiopods are *Spiriferina Stracheyi, Dielesma* and *Rhynchonella*; the gasteropods are represented by a species of *Euomphalus* and the aberrant genus *Conularia.*

Upper Trias.

The Muschelkalk is succeeded, in all the above-noted localities, by an enormous development of the Upper Triassic strata, which are mostly unfossiliferous, but for a zone of lamellibranch- and brachiopod-bearing beds included at its lower part. An Upper Triassic crinoidal limestone is widely distributed in moraine heaps clothing the N E. slopes of the Pir Panjal, but for the greater part the formation is an unvarying succession of thick massive unfossiliferous limestone It is this limestone which builds the range of high hills and precipices so conspicuous by their colouring in the Vihi and the Islamabad districts.

The Triassic limestone has furnished an excellent building material to the architects of ancient Kashmir in the building of their great temples and edifices, including the world-famous shrine of Martand.

The fauna of the Upper Trias is quite poor in comparison to that of the Lower and Middle divisions. Cephalopods are almost absent. The few lamellibranchs comprise *Myophoria, Gervillia, Pseudomonotis, Lima, Pecten, Pleurophora, Trigonodus.* The brachiopods are *Spiriferina Haueri, Dielesma, Rhynchonella,* etc. The absence of the well-marked *Halobia* and *Daonella* zones, and the numerous and highly diversified race of cephalopods of the Spiti Upper Trias from this area, suggests some sudden and effective interruption in the free intercourse and migrations of species that had existed between the seas of the two areas for such long ages. This intercourse appears to

Relation of the Kashmir and Spiti provinces during the Upper Trias.

'e been partly re-established during the Jurassic, though on the former scale, for the fauna of the later ages that been discovered in Kashmir up to now, is quite scanty impoverished in comparison with the Spiti fauna.

JURASSIC

The Jurassic of Ladakh.

ı the Spiti area, which in reality is the direct south-east ›nsion of the Zanskar area of the Kashmir basin, it will be embered the following sequence of Jurassic deposits is wn :

umal sandstone.		Cretaceous.
ti shales		Jurassic.
›to limestone.	*Tagling stage*, including the Sulcacutus beds. *Para stage*, including the Megalodon limestone.	
›notis shales.		Triassic.

sequence, roughly similar in many respects to this, is ›able in some outcrops in the Central and Southern parts ıdakh, resting conformably upon the Upper Triassic lime-›. These outcrops form part of a broad basin of marine ›zoic rocks situated upon the inner flank of the Zanskar ›, and are connected with the Jurassic formation of Spiti ›ing on the same strike. The lower parts of a number of outcrops, which include about 500 feet of dolomitic tone, recall the Megalodon limestone, both in their con-ıon and in their fossil contents. At another locality group is succeeded by light-blue limestone, which from ›ntained fossils is referrable to the Tagling stage [1] The ng stage passes conformably up at several localities into piti shales, that eminently characteristic Jurassic horizon malayan stratigraphy. It is readily recognised by its

[1] o accuracy of this correlation, it must be realised, has never been ntly ascertained. Middlemiss' revision of the Kashmir sequence far proceeded only up to the Trias. It is only when this work is ted that a full account of the Jurassic of Kashmir can be given in tail such as we have given above of the Palaeozoic formations The ı to be said about the Cretaceous.

peculiar lithology, its black, thin-bedded, carbonaceous and micaceous shales containing a few fossil-bearing concretions. The following fossils have been hitherto obtained from the Jurassic of Ladakh

Megalodon, *Avicula*, *Pecten*, *Cerithium*, *Nerinea*, *Phasianella*, *Pleurotomaria*; some *Ammonites*, including *Macrocephalus* and numerous fragments of *Belemnites*; with a few species of *Rhynchonella* and *Terebratula*.

With the exception described below, the Jurassic system has not been recognised in the Kashmir province proper. It

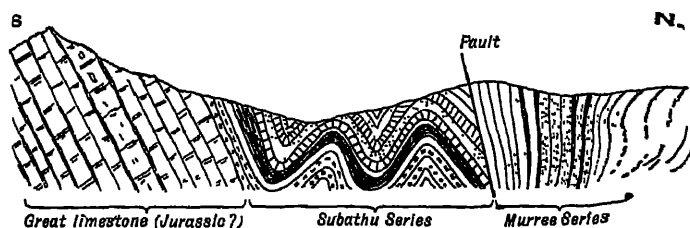



FIG 36 —Subathu series of Jammu.

is probable that the more detailed survey of the province, which is being prosecuted at the present time, will bring to light further outcrops of this system from remoter districts.

uc of al. Within late years one such outcrop of the Jurassic system was noticed at Banihal, on the Pir Panjal, and at Vernag by the Geological Survey. A series of limestone, shales and sandstones therein, resting on the topmost beds of the Upper Triassic, have yielded distinct Jurassic fossils.

sic of u. A large and massive outcrop of Jurassic (?) limestone occurs in a number of inliers in the outer or sub-Himalayan zone forming the Jammu hills. This is a very unusual circumstance, which finds only one parallel in the Tal series of the Nepal Himalayas. Here fairly large masses of Jurassic limestone are laid bare by the removal of the overlying Murree series from the anticlinal tops. The most notable of the inliers thus exposed forms a conspicuous hill-mass near Jummu (the Trikuta hill). It is of the shape of an irregular oval with a general W.N.W. to E S.E axis, faulted on its steep southward scarp against the Siwaliks of Jammu The limestone is a bluish, extremely compact and cryptocrystalline siliceous

imestone, entirely barren of organic remains throughout its nass. It is interbedded at places with thin flaggy, cherty lates, and at the top there is a prominent band of siliceous reccia. The Jurassic age of this limestone is inferred on thological grounds only, from its general resemblance to the nassive Jurassic limestone of Ladakh, the "great limestone," s it is termed by some authors.[1]

CRETACEOUS

If the account of the Jurassic system of Kashmir is meagre, hat of the Cretaceous rocks is still more so. It is only at few localities that rocks belonging to this system have been iscovered; all of these lie in a distant unfrequented part of outh-east Kashmir, in the Rupshu province. The great evelopment of the Cretaceous rocks of Spiti and its surrounding places, the Giumal sandstone, the Chikkim limestone and ie enormous flysch-like series, have not been observed in ashmir, though from the fact of their occurrence in the estern province of Hazara, it is probable that these series ight have their parallels in Kashmir in a few attenuated itcrops at least.

The Chikkim series of Rupshu-Zanskar.

Two or three small patches of Cretaceous rocks occur in upshu which correspond to the Chikkim series in their ological relations. They are composed of a white limeone, as in the type area, forming some of the highest peaks ' the range in Ladakh. No fossils, however, have been btained from them hitherto.

Drew has recorded the occurrence of *Hippurite* limestone, Cretaceous age, in the Lokzhung range of mountains, on e furthest northern boundary of this State. Another dication of a Cretaceous formation in the Ladakh province furnished by the discovery of the Cretaceous fossil, *yphea vesiculosa*, at a place Sajna, on the road from h (the capital of Ladakh) to Yarkand, from a group of lcareous sandstones. Stoliczka has also recorded the currence of *Hippurite* shells in some parts of the same proice. It is probable, therefore, that the detailed examination

[1] Medlicott: *Rec. G.S.I.* vol. ix. pt. 2, 1876.

of the country at present in progress may disclose a well-formed Cretaceous series in these parts.

TERTIARY

Introductory

The Tertiaries of Kashmir call for no special notice beyond the few local peculiarities which they exhibit. The Tertiary band at Jhelum stretches eastwards through the Kashmir area, preserving all its geological characters and relations unchanged, to the Ravi, where it merges into the much better explored country of the Simla Himalayas. Structurally, however, one feature of distinction emerges, and that is the disappearance of the Main Boundary Fault as a limit of deposition between the Murrees and successive Siwalik zones to the west of the Ravi; the more northerly fault-plane junctions, however, between the older Tertiaries and the still older Himalayan rocks yet preserve their boundary nature. This tract of hilly country of low elevation, lying outside the Pir Panjal, and comprised between the Jhelum and Ravi, is designated the Jammu hills The Tertiary outcrop is widest where it is crossed by the Jhelum, but is much constricted at its eastern boundary at the Ravi.[1]

The remaining account of the geology of Kashmir pertains to the Jammu province, whose geology is almost entirely composed of Tertiary rocks with the exception of a small area of crystalline rocks in the Kishtwar and of Jurassic limestone in the Riasi district. The few districts situated on the Pir Panjal belong geologically to the Kashmir province.

Tertiaries of the Inner Himalayas—the Indus Valley Tertiaries.

A most noteworthy event, already briefly hinted at, in the Tertiary geology of Kashmir, was the occupation of a small area in Ladakh by the waters of the retreating Tethys. This sea has left a basin of Lower Tertiary deposits, in a long, narrow tract in the Upper Indus valley from Rupshu to Kargil. The existence of marine Tertiary sediments to the north of the Himalayan axis must be regarded as a very exceptional circumstance indeed, for nowhere else (except once in Hundes), from Hazara to the furthest eastern extremity of the Himalayas, are sedimentary rocks younger in age than Cretaceous seen beyond the high ranges

[1] *Rec G S I* vol. ix. pt. 2, 1876.

'The Tertiaries of Ladakh rest unconformably over gneissic nd metamorphic rocks The base is of coarse felspathic rits and conglomerates, followed by brown calcareous and reen and purple shales The shales are overlain by thick band of blue shelly limestone, containing ill-reserved *Nummulites*. This nummuliferous limestone is ucceeded by a coarse limestone-conglomerate. On either xtremity of this sedimentary basin there is a large de-elopment of igneous rocks of an extremely basic com-osition. They include both contemporaneously erupted ark basalts with ash and tuff-beds, as well as dykes and lls of intrusive peridotites.

The sedimentary part of this group has preserved a few ssils, besides the *Nummulites* noticed above, but owing to ie great deal of folding and fracturing which they have ndergone the fossils are mostly deformed and crushed beyond cognition. The following genera are identified, with more · less certainty. *Unio* and *Melania,* in the lower part which bear witness to estuarine conditions), and *Nummulites, amites, Hippurites, Conus,* etc., which yield very discrepant idence as to the age of the enclosing group.

The Tertiaries of the Jammu hills

The systems of strata constituting the Tertiary zone of the mmu hills are disposed in three or four parallel belts con-rming to the strike of the hills; the oldest of these abut on e Pir Panjal, and constitute its south-west flank ridges, iile the newer ones occupy successively outer positions ilding the low ranges of the Murree Siwalik foot-hills. here the Chenab leaves the mountains at Akhnur, there is deep inflection of the strike of the hill-ranges; the same iture is repeated, but on a far larger scale, at Muzufferabad, the emergence of the Jhelum. At this point the strike of e whole Outer Himalayan system undergoes a more profound nding inwards. The re-entrant bay thus produced is an ite-angled (40°) triangle with its apex thrust forward arly a hundred miles from the base-line. The exact signi-ance of this feature is not thoroughly understood, but it probably due to some crustal obstruction which has deflected main axis of the fold-systems and converged them in a ot (Syntaxis).

The accompanying table shows the relations of the Tertiaries of Jammu hills to the corresponding rocks of the Simla hills and other parts of India :

	(Jammu.) *(N W. Himalayas.)*	(Simla.) *(C. Himalayas.)*	*Other parts.*
Siwalik system.	Upper Siwalik. Conglomerates, clays, grits, etc.	Upper Siwalik.	Siwalik of the E. Himalayas; Irrawaddy series. Upper Manchar of Sind.
	Middle Siwalik: Sand-rock.	Middle Siwalik.	Siwalik of the Salt-Range; Kangra; Potwar; and the N.W. Frontier Provinces.
	Lower Siwalik. Chinji stage. Kamlial stage.	Lower Siwalik (or Nahan).	
	Upper Murree · Soft sandstones, purple shales.	Kasauli series.	Pegu series of Burma; Mekran system of Baluchistan; Cuddalore sandstone of the East coast.
	Lower Murree Hard, dark sandstones, red and purple shales.	Dagshai series.	
	Fatehjang beds · Ossiferous sandstones.		Bugti beds; Nari and Gaj series of Sind.
	Subathu or Chharat series :	Subathu series	Kirthar series of Sind, Assam, Cutch, Salt-Range.
	Nummulitics of Jammu and Poonch, Indus Tertiaries.	Shales and thin limestones.	Laki series of Sind, Assam, Cutch, Salt-Range. Nummulitics of Gujarat.
	Coal-measures. Laterite bauxite	Pisolitic limonite.	
	Ranikot stage of Pir Panjal.	——	Ranikot of Sind; Burma and Hazara.

EOCENE

The Eocene of Kashmir exhibits a double facies—one analogous with the Nummulitics of Hazara and N.W. Punjab and the other recalling the Subathu facies of the type area in the Simla hills. The former type is well developed in the south-west flank of the Pir Panjal wherein, along its whole length from the Jhelum to the Ravi, it constitutes a remarkably consistent and characteristic belt of altered, obscurely nummulitic limestone of the " Hill Limestone " facies, overlaid by a thick series of variegated shales with coal seams at the base (Chharat Series). Lydekker ascribed these rocks to

an indefinite age between the Carboniferous and Trias, and named them "Kuling" and "Super-Kuling" series; late work in the Poonch area, however, has established the Eocene age of these rocks beyond doubt.[1]

The Subathu series of Jammu.

The Subathu type of the Eocene is met with in a number of inliers exposed in the Murree zone lying to the south of the Pir Panjal The most important of these inliers occurs as a narrow rim bordering the outcrop of an older unfossiliferous limestone exposed as the core of an anticlinal near Riasi, north of Jammu. Another is seen in Poonch exhibiting like relations.

The section given below illustrates the sequence of formations in the Subathu type of the Eocene :

Lower Murree (Some thousand feet).	Purple and grey sandstones and shales of great thickness underlaid by ossiferous pseudo-conglomerates.
Subathu (300-600 ft.).	Nummulitic limestone, thin-bedded. Olive shales Nummulitic limestone. Grey and olive shales. Pyritous shales. Ironstone shales, carbonaceous. Coal seams (6 in. to 20 in.) in pyritous shales. Pisolitic bauxite and limonite clays, 6-10 ft.
	Dykes of ultra-basic intrusive
Unconformity.	~~~~~~~~~~~~~~~~~~~~
Jurassic (?).	Chert breccia, 6 ft.-10 ft. White cherty and silicified dolomitic limestone, unfossiliferous ("Great Limestone"), thickness over 1000 ft.

These inliers are exposed as the cores of faulted anticlinals in the Murree series, the north limb of which shows conformable passage of the Eocene into Murrees, while the south limb is generally missing as the result of strike-faulting.

Eocene bauxite.

The basal beds of the Eocene are highly interesting as containing evidence of an extensive laterite formation, which appears variably at different places, either as a pisolitic limonite or as a pure bauxite. The laterite or bauxite covers an old land surface of the pre-tertiary limestone, and marks a great erosional unconformity. In the valley of the Poonch, near Kotli, the base of the Eocene rests on the truncated edges of nearly vertically inclined strata of the "Great Limestone," but this discordant junction is not equally apparent everywhere.

The pisolitic limonite and ironstone of Riasi and Poonch

[1] D. N. Wadia, "Geology of Poonch," *Mem. G.S.I.* (in the press).

have been largely drawn upon in the past to support a flourishing industry of iron-smelting, while the associated bauxite deposits of these localities form large potential reserves of a high-grade ore of aluminium. At Riasi the overlying coal-measures have been found to be workable and capable of supporting remunerative mining, but further westward the coal is excessively friable, and distributed in very thin and inconstant seams which are severely crushed and in part graphitised.

The nummulitic limestone is thin-bedded and black-coloured, it has a tendency to assume greater proportion as it is traced westwards of the Jhelum, in which direction the constitution of the whole series changes materially The coal-seams become thinner and then disappear, the pisolitic iron-ore and bauxite are barely seen, while the nummulitic limestone steadily increases in bulk, becoming a massive monotonous formation of white or pale colour, whose aggregate thickness is over 1600 feet The species of Nummulites so far identified in these rocks are: *N. beaumonti, N atacicus, Assilina granulosa*

Eocene of the Pir Panjal.

The Eocene of the Pir Panjal probably belongs to a lower horizon, though its base is not exposed anywhere The limestones are about 200–400 feet thick, generally thin-bedded and lenticular, containing obscure tests of *Nummulites* and *gastropoda*; they show a general resemblance to the "Hill Limestone" of the Punjab and Hazara (Ranikot age). A typical section shows:

Metamorphosed older Palaeozoic rocks, or Murree Series.

——————— Thrust-plane.

Laki (*Chharat*).	Variegated red and green shales with quartzose sandstones, - - -	800 ft.
	Thin-bedded lenticular, black bituminous limestones with *Nummulites, Operculina, Assilina* and *Ostraea*, - -	100 ft.
	Coaly and pyritous shales with ironstone shales and jasperitised beds, - -	50 ft.
Ranikot	Massive, pale, grey-coloured, cherty, generally thin-bedded limestones, with badly preserved *Nummulites* and *gastropoda*, - - - -	300-400 ft.
	Shale partings very few.	

Unconformity. ~~~~~~~~~~

Panjal Trap and Permo-Trias limestones.

It is probable that this limestone group extends in a continuous outcrop along a general north-west direction from the northerly termination of the Panjal chain near Uri, along

the Jhelum valley to Muzzaffarabad, and thence to Hazara, merging into the wider Eocene zone of that region.

MURREE SERIES

Lower Murree series. The Murree series is a thick pile of purple and grey, fine-grained, indurated sandstones, very slab-like and compact in aspect, alternating with purple and red splintery shales and repeated bands of concretionary clay pseudoconglomerates This group everywhere exhibits isoclinal type of folding, and hence its true thickness is difficult to estimate, but it is probably between 4000–5000 feet. This great thickness of often deeply ferruginous, unfossiliferous sediments points to a lagoon mode of deposition, to which fresh-water had no or very rare access, and in which the concentration of the calcareous matter in solution at times reached the stage of precipitating beds of impure limestone. Proof of a temporary return of clear water marine conditions is afforded by a series of fossiliferous bituminous limestones and calcareous shales containing a fauna very like that of the Upper Chharat stage of Rawalpindi, which have been lately found interstratified with lower Murree series in Poonch

A few *palm* and *dicotyledon* leaf impressions and silicified wood remains are all the fossils hitherto observed in the main body of the group. At the base, however, some 100 feet of ossiferous sandstone and conglomerate occur—the Fatehjang zone— containing *Anthracotherium*, *Teleoceras* and *Brachyodus*, which indicate close affinities with the Bugti beds fauna. **Fatehjang zone**

The Murree outcrop is over 25 miles wide where it crosses the Jhelum, but it thins eastwards rapidly, and where it intersects the valley of the Ravi it is only 3–4 miles across. At this point it merges into the Dagshai series of the Simla region. On lithological grounds the series is divisible into Lower and Upper stages of variable thickness ·

Upper Murree	Soft, brown and buff, coarse, sandy sandstones, with inner cores of grey colour Red and purple shales and nodular clays Numerous *di-* and *mono-cotyledon* leaf impressions.
Lower Murree	Indurated, deep-coloured, at times inky purple and red sandstone, generally flaggy. Splintery, purple shales and deep red clays, with abundance of vein calcite. Numerous bands of pseudoconglomerates Unfossiliferous, except at base, where a few beds are ossiferous,

Structurally and in their field relations the Upper Murrees present aspects of Siwalik type—open, broad folds weathered into strike-ridges and valleys with a succession of escarpments and dip-slopes, while the Lower Murrees show far greater amount of compression, fracture and dislocation, being plicated in a series of tight isoclines and overfolds with repeated local faulting. They weather in the fashion of older rocks which are cleaved and jointed, and with which the lineation of spurs and ridges have no close relation to the prevalent strike or " grain " of the country.

The inner limit of the Murree group is as usual a great thrust-fault where it abuts upon the older rocks of the Panjal range—a structural feature which, as already referred to, is not repeated at its outer limit—the junction of the Murrees with the outlying Siwalik group.

SIWALIK

Rocks of the Siwalik system are disposed in parallel folded zones constituting the outermost foot-hills, which have a width of some twenty-four miles. The Siwalik system of the Jammu hills does not differ in any essential respect from that developed in the rest of the Himalayas from Afghanistan to Assam Structurally, stratigraphically, as well as palaeontologically, they exhibit similar characters, broadly speaking, to those found in the better-surveyed areas to the east and west of it. No detailed work or systematic collecting of fossils, however, has yet been made in those hills, as has been the case with the same series of deposits in the Siwalik hills, Kangra and Salt-Range, which have yielded relics of the highest value, bearing on the problem of the phylogeny of Mammals

The Siwalik group of the Jammu hills is classified into Lower, Middle and Upper, but the respective limits of these divisions are not certain owing to the meagreness of the palaeontological evidence. On the whole, while the Upper and Middle Siwaliks of the Jammu hills show a more or less close lithological analogy with those of the adjacent Salt-Range and Potwar areas, the lower division exhibits marked local variations, which relate them more nearly to the Murrees than to the typical Kamlial or Chinji facies This persistence of Murree conditions of deposition during Lower Siwalik time becomes more marked nearer the Jhelum valley, in the Poonch area where, between the Upper Murrees and the basal beds of the Lower Siwaliks there is no difference whatever

of rock-facies, save the local occurrences of fragmentary bones of fresh-water reptiles and mammals in the latter group.

Lower Siwalik.

Petrologically the Lower Siwaliks are composed, from the bottom upwards, of indurated brown sandstones liberally intercalated with thick strata of red and purple semi-nodular clays having a general resemblance with the Upper Murrees on the one hand towards the west and the typical Nahans of the Simla hills towards the east. The lower harder and more purple coloured beds, about 4000 feet in thickness, possess a fauna of Kamlial age, though of a very meagre description. The upper, scarcely less indurated, but more shaly division, is of less vertical extent, and is characterised by a newer fauna of Chinji type, in the few localities from which fossils have been collected Fossil plants and woody tissue is met with abundantly in the lower part, together with bones of a varied reptilian population of *Chelonia*, *Crocodilus*, *Gharialis*, fishes and snakes, mixed with gastropod shells and their *opercula*. The upper division has yielded numerous *Rhinoceroses*, *Mastodon*, *Dinotherium*, *Perissodactyle* ungulates, several species of *Anthropoid-apes*, *Antelopes*, *Giraffes*, and several genera of the *Suidae* and *Anthracotheridae*.

Middle Siwalik.

Overlying this group there come the Middle Siwalik group of thick massive beds of coarse micaceous sand-rock, too incoherent to be termed sandstone Clays and shales are sparingly developed in these, and they have not the bright vivid colouration of the shales of the lower division. The prevalent colour of the sand-rock is pepper-and-salt grey. Its cementation is very unequal, much of the cement being concentrated in large, hard, fantastically shaped concretions which at times enclose fossil teeth, skulls or bones, leaving the main part of the rock a crumbling mass of sand. Pebbles are found, and increase in numbers and size, as the upper limit of the Middle Siwalik series is reached, till they form enormous beds and lenticles of coarse bouldery conglomerates. Several species of *Mastodon*, *Stegodon*, *Rhinoceros*, *Hipparion*, and *Sus* have been found from these rocks.

Upper Siwalik.

The Upper Siwaliks consist lithologically either of very coarse conglomerates, the boulder-conglomerate, or massive beds of sand, grit and brown and red earthy clays The former occur at the points of emergence of the large rivers—the Ravi, Tavi, Chenab and Jhelum and of their principal tributaries—while the latter occupy the intervening ground The clays are in the upper part of the series, indistinguishable

from the alluvial clays of the Punjab plains into which they pass by a perfectly conformable passage upwards

Fossils are numerous in the Upper Siwaliks at some localities. This area appears to have been a favourite haunt of a highly diversified elephant population, as is evident from the profusion and wide distribution of their skeletal remains. Incisors of *Elephas*, *Stegodon*, *Mastodon*, their molars, skull plates, mandibles, maxillae, limb-bones, etc., are commonly found in the sands and conglomerates Other fossils are referable to *Bubalus*, *Bos*, *Hippopotamus*, *Rhinoceros*, *Sus*, *Equus*, *Cervus*, *Apes*, *Gharials* and numerous *Chelonian* bones

The precise boundary of the various Siwalik divisions described above cannot be delimited in the absence of positive or sufficient fossil evidence, nor is more minute sub-division into stages and zones possible The inner boundary of the Siwaliks is, as stated above, a faulted one only as far as the Chenab, beyond which, westwards, the fault gradually diminishes and is replaced by an anticlinal flexure The parallel boundary faults within the Siwalik zone of the Eastern Himalayas (Figs. 28 and 29), are not observed in the foot-hills west of the Ravi, the system of strike-faults that is met with in this area is of the nature of ordinary dislocations, and have no significance as limits of deposition

Physiography of Siwalik country. The weathering of the Siwalik rocks has been proceeding at an extraordinarily rapid rate since their deposition, and strikingly abrupt forms of topography have been evolved in this comparatively brief period Gigantic escarpments and dip-slopes separated by broad longitudinal strike-valleys and intersected by deep meandering ravines of the traverse streams—surface-features which are the most common elements of Siwalik topography—give us a quantitative measure of the subaerial waste that has taken place since the Pleistocene. The strike is remarkably constant in a N.W.-S.E. direction, with only brief local swerves, while it is almost always in strict conformity with the axes of even the subordinate ridges and elevations. The only variations in strike-direction from this course are the ones already referred to.

Although the Siwalik strata are often highly inclined, especially towards their inner limits, they are never contorted or overfolded, as is the case with the Murrees

PLEISTOCENE AND RECENT

Pleistocene or post-pliocene deposits of the nature of fluviatile, lacustrine or glacial, have spread over many parts

Kashmir and occupy a wide superficial extent. Of these most interesting as well as conspicuous examples are the h-water (fluviatile) deposits found as low flat mounds dering the slopes of the mountains above the modern vium of the Jhelum.

Karewa series.

'hese are known as Karewas in the Kashmiri language. Karewa formation occupies nearly half the valley; it a width of from eight to sixteen miles along its south-t side and extends for a length of some fifty miles from pyan to Baramulla. The earlier view regarded the 'ewas as the surviving remnants of deposits of a lake or es of lakes which once filled the whole valley-basin from to end The draining of the lake or lakes, by the opening subsequent deepening of the outlet at Baramulla, has them bare to denudation which has dissected the once tinuous alluvium into isolated mounds or platforms. ing into consideration, however, the enormous thickness the Karewa deposits revealed on the north-east Panjal es, viz 4500 feet, many observers consider the lake theory heir origin untenable except for the upper portion of these osits. Middlemiss suggests that the lower part of the 'ewas must have had an origin similar to the Siwaliks and is old as the Pliocene—a local type of the Upper Siwalik osits on the inner side of the Panjal chain. Recent work ws that between the lower sandy and upper bouldery or velly divisions of the Karewa series there is a marked onformity of deposition.

Structural features.

he Karewas are mostly horizontally stratified deposits sisting of beds of fine-grained sand, loam, blue sandy clay i lenticular bands of gravelly conglomerate. Inter-tified with the top beds are thin seams of lignite or wn coal which are of workable proportions at two or three lities Only when they abut upon the slopes of the Pir ijal do the Karewas show dips of from 5°-20°, away from mountains, indicating that they have shared in the later eaval of the Panjal range. Recently dips of over 40°, i sharp monoclinal folding, have been observed, while series has been traced continuously up to almost the imit of the Pir Panjal. This fact establishes the inference t the Pir Panjal has undergone considerable elevation since material of the Karewas was laid down on its slopes.

'ossil leaves and wood of recent species, together with land fresh-water shells and some vertebrate remains, are nd at numerous places.

Glacial moraines.

Pleistocene and later glacial deposits are of wide distribution in Kashmir. Two distinct sets of moraines are observed—one at high level, which is of more recent accumulation by existing glaciers, and the other at considerably lower situations,

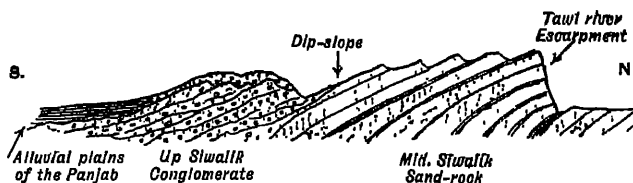
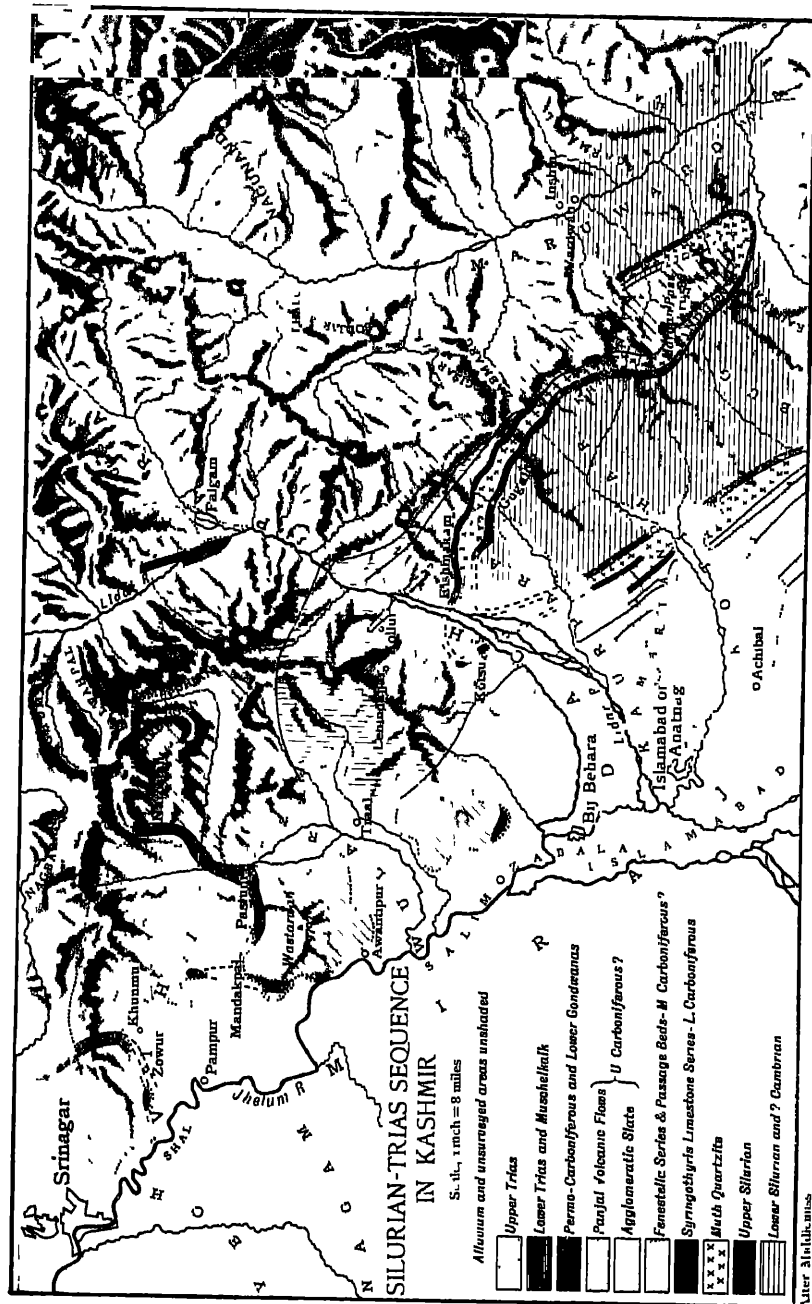
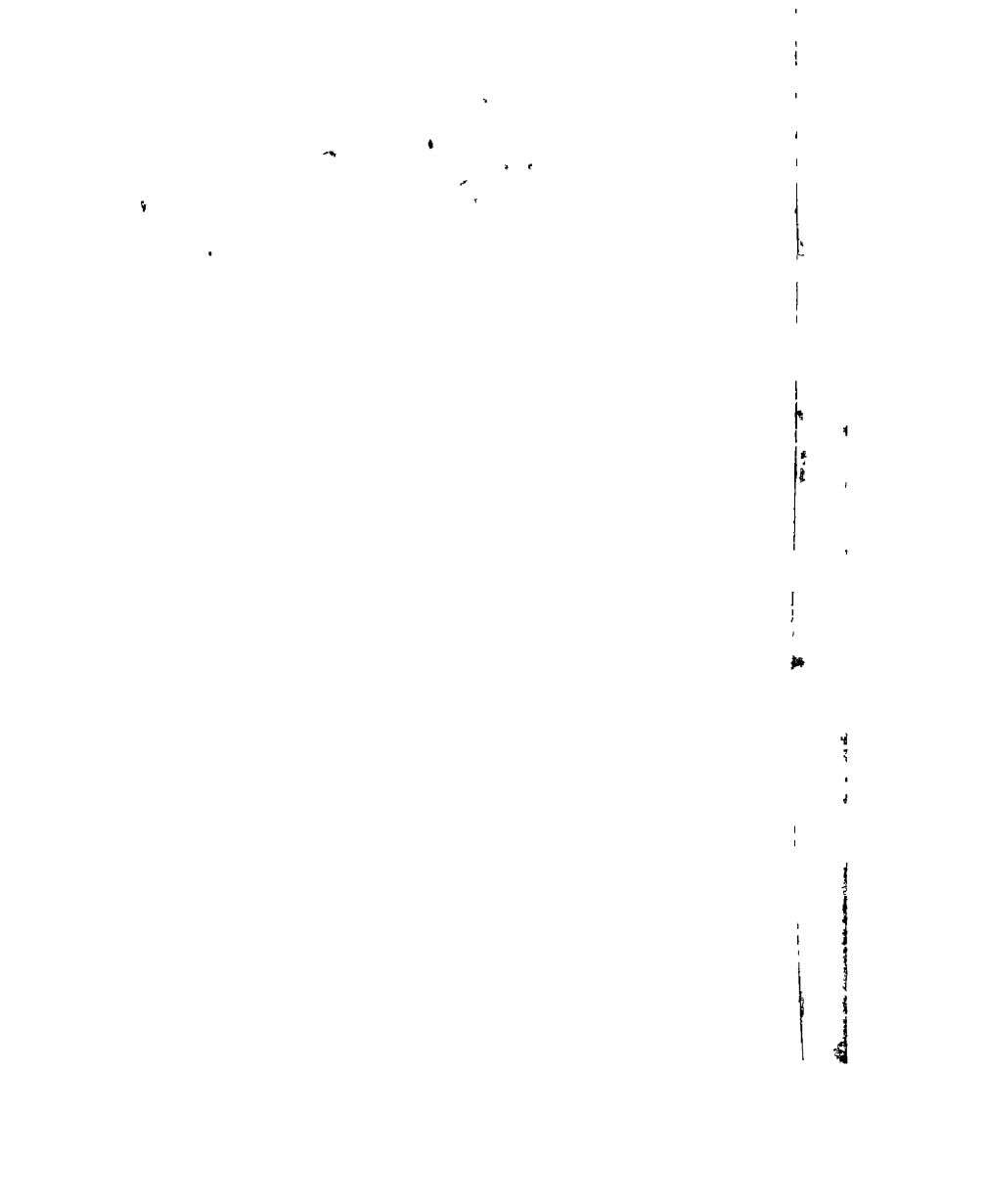



FIG. 37.—Section across the outermost hills of the Sub-Himalayas at Jammu. Note the succession of dip-slopes and escarpments

whose age is Pleistocene. On both faces of the Pir Panjal moraine masses *in situ* are met with at levels above 6000 feet, while reassorted moraine débris has filled up the higher reaches of the valleys below this level. Typical cirque-like amphitheatres with steep cliff-faces are met with at two or three localities in the Poonch Pir Panjal.

High-level river-terrace

Among later deposits than these are the high-level river-terraces, 1000 feet or more above the stream-bed, sub-recent river alluvia, levees, and flood plains; the enormous "fan-taluses" in the Nubra and Changchenmo valleys of Ladakh; cave-deposits such as those of Harwan; travertine, etc.

The great thickness of gravel and pebble-beds, resting unconformably over the subjacent Upper Siwalik boulder-conglomerate which fringe the outermost foot-hills of the Jammu hills, is likewise of the same age.

(After Middlemiss. From *Geological Survey of India, Records*, vol xl pt 3)

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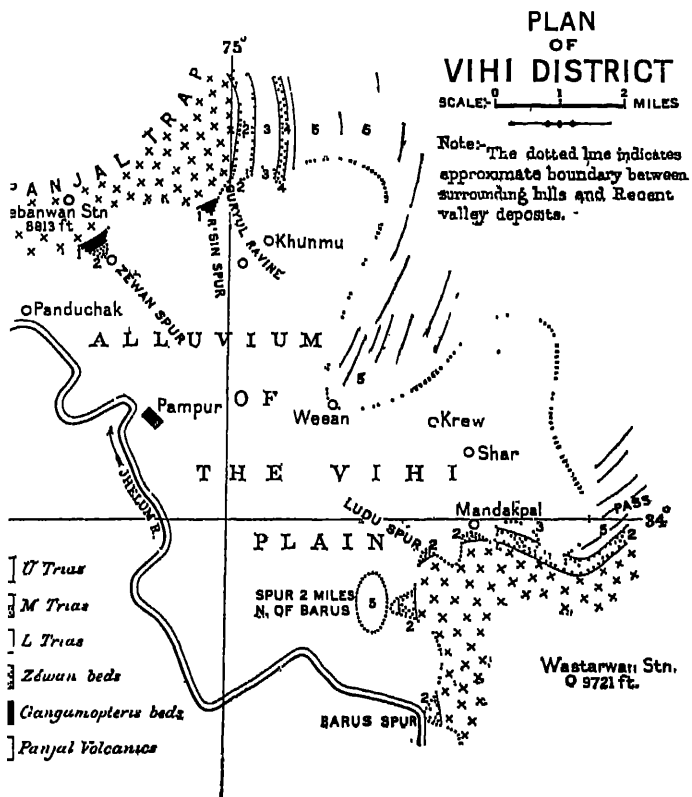
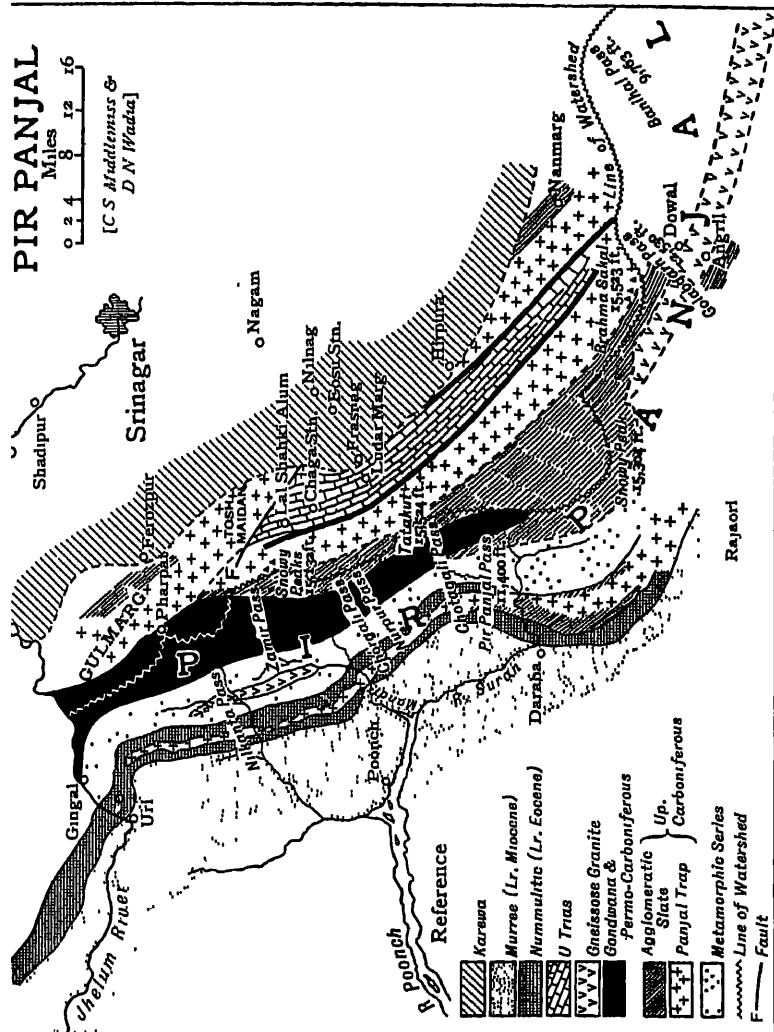

(Middlemiss, *Geol Survey of India, Records*, vol. xxxvii pt. 4)

(Geol Survey of India, Records, vol xli pt 2)

78°
80°
16°
14°
Kistna R.
Srisailam
Irlakonda
Budavada
Kurnool
Pavalur
Vemavaram
Bairenkonda
Cumbum
Paniam
Nandyal
Banganapalli
Koil-Kuntla
Owk
Tadpatri
Kundair
Jammalamadugu
Narji
Cuddapah
Nellore
Pulivendla
Papaghni
Vampalli
Gulcheru
Cheyyeru
Pullampet

Para R.
Tagling Pass
Kioto
Chikkim
Giumal
Lilang
Po
Kuling
32°
32°
Muth
Lipak R.
S P I T I
Babeh Pass
Sutlej R.
SIMLA
Boileauganj
Bioini R.
Krol
Subathu
Kasauli
Dagshai
S I R M U R
Nahan
J A U N S A R
Mandhali
Deoban
Chakrata
Ganges R.
Niti

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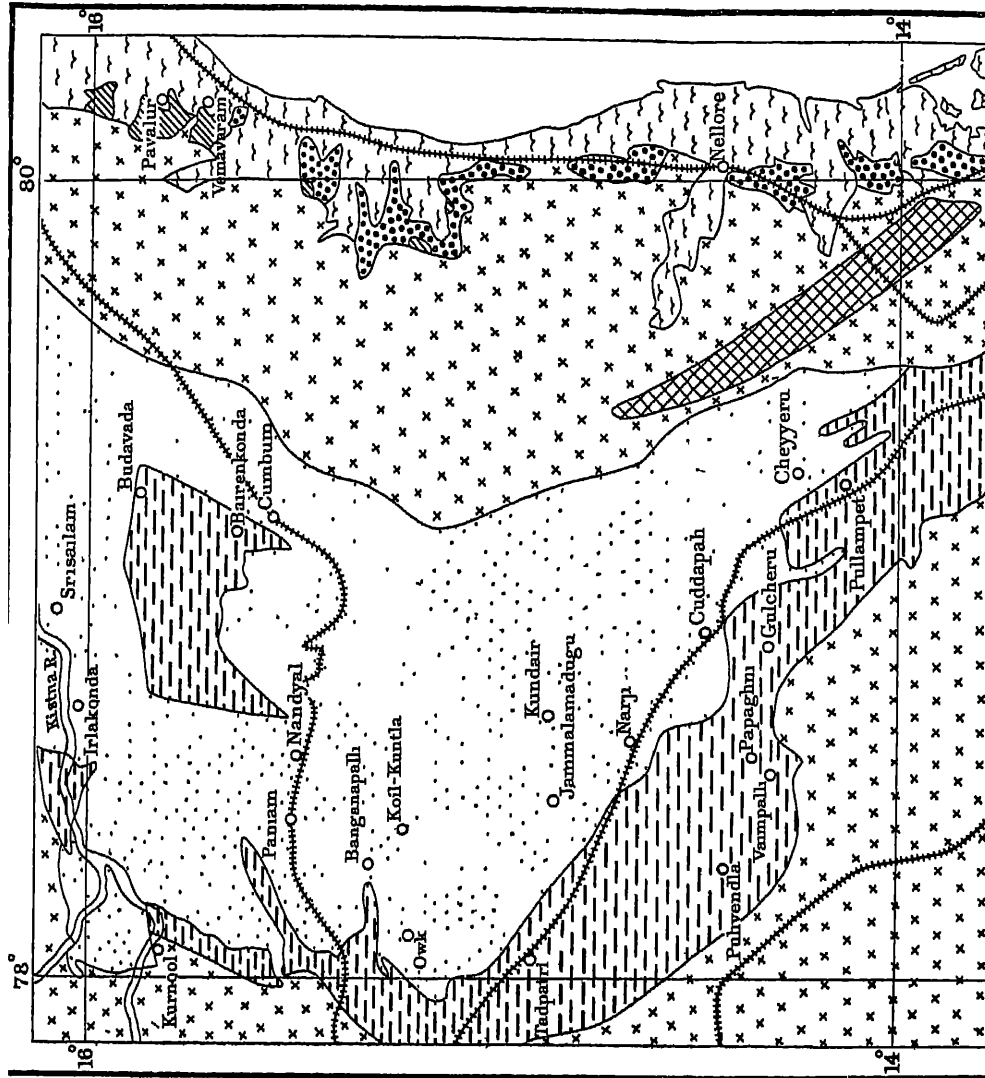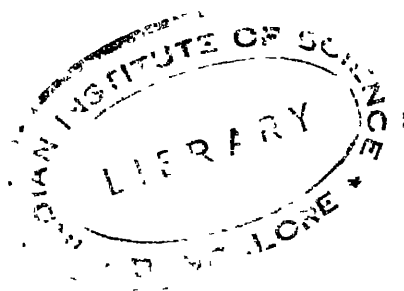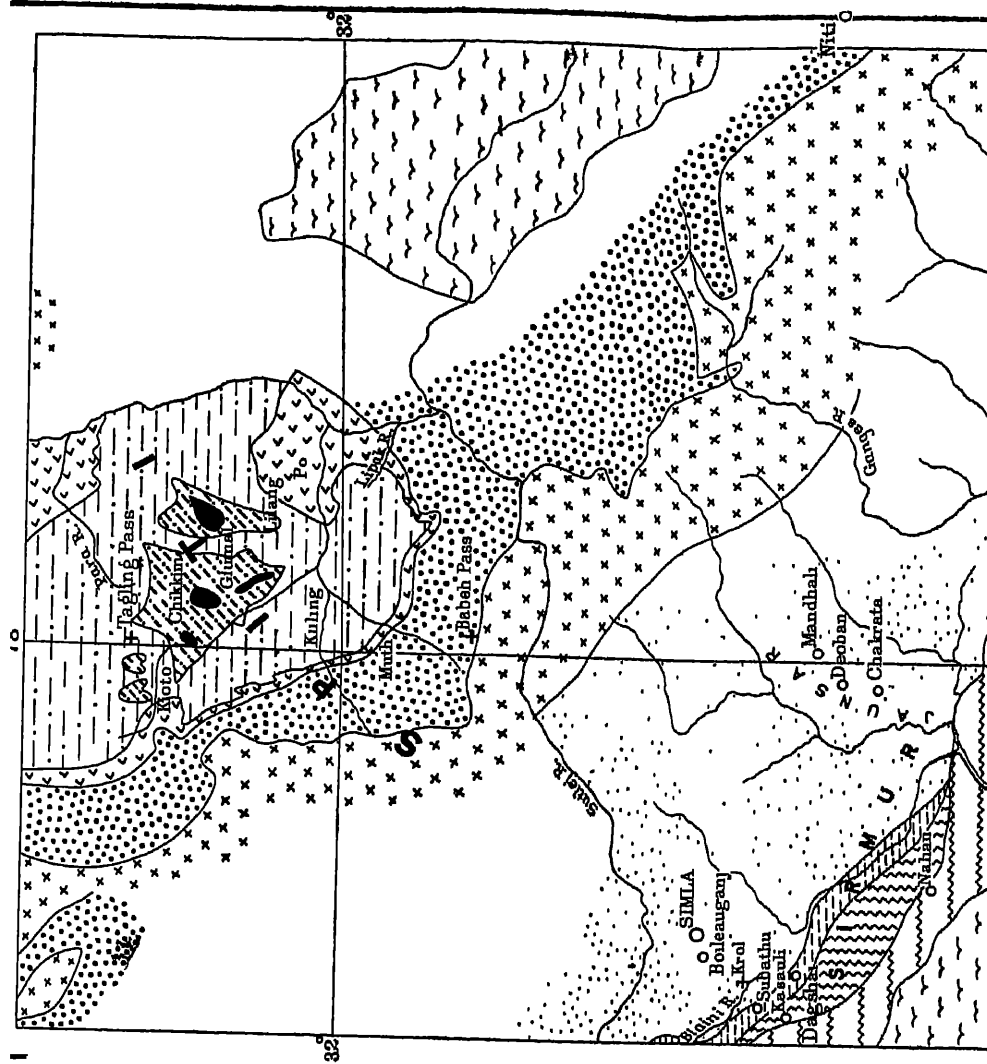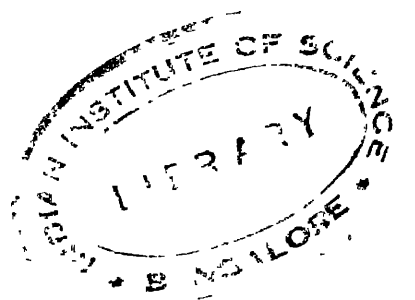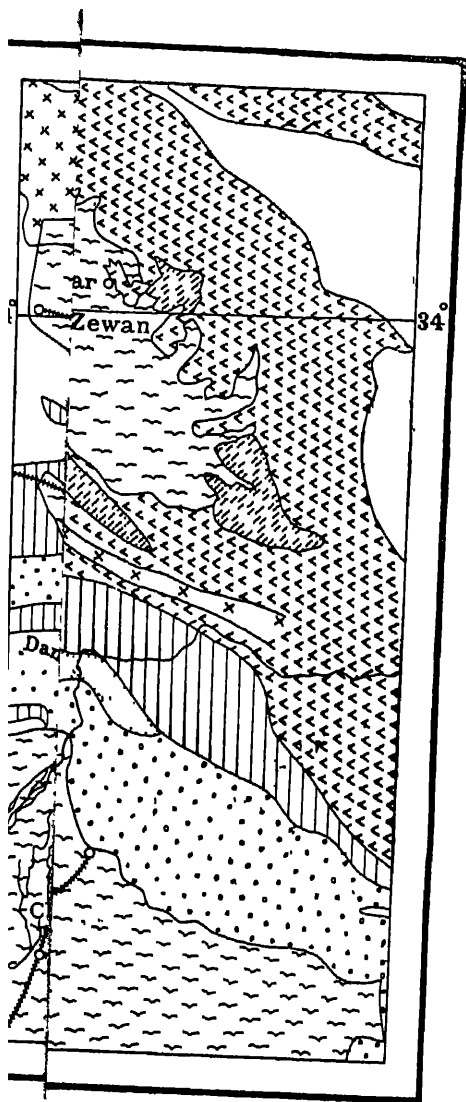
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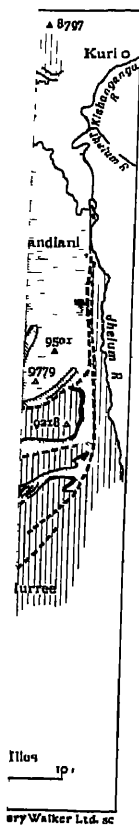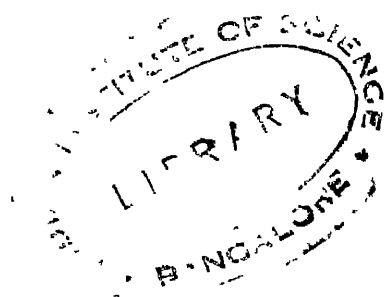
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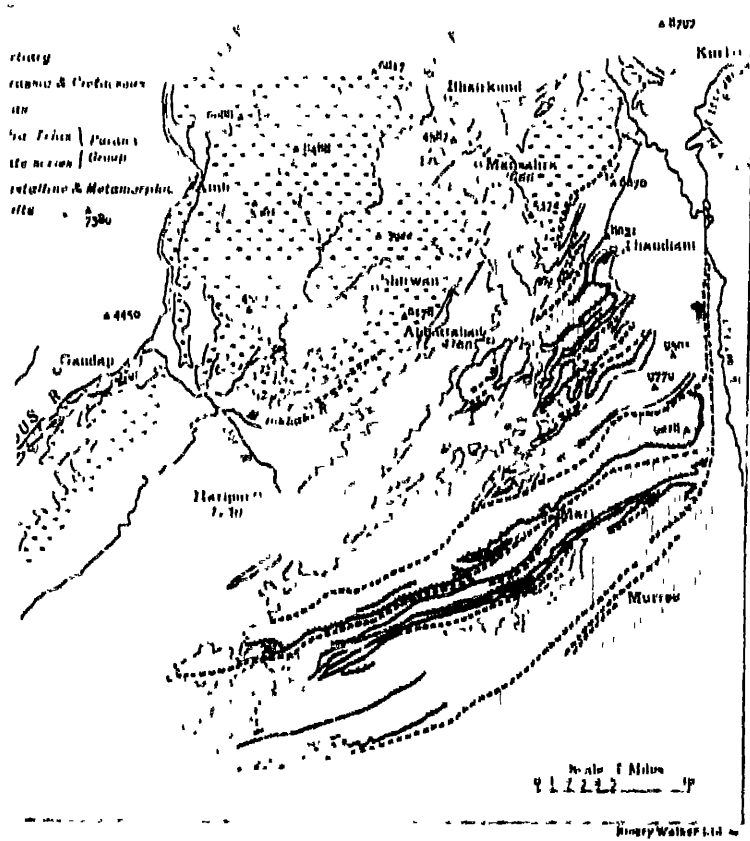
GEOLOGICAL MAP OF HAZARA.

(After C. S. Middlemiss, *Mem. Geol. Survey of India*, xxvi.)

Bawdwin

Mogok

Lashio

W.G.I.

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